

SYNOPTIC AND MESOSCALE ANALYSES OF A FLASH FLOOD EVENT IN EASTERN IDAHO

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ABSTRACT

This study documents the synoptic and mesoscale conditions of a flash flood episode which occurred on 18 July 2004 in eastern Idaho. The climatological Type III synoptic pattern for the western United States documented by Maddox et al. (1980) was in place during the heavy rainfall event. Environmental conditions of deep warm cloud layers, low wind speed shear, small wind directional shear, moderate to high convective instability, and upstream shortwave triggers contributed to heavy rainfall and flash flooding in the region of study.

Convection developed during the early afternoon hours (1200 MDT or 1800 UTC) and propagated slowly downstream in the mean southwest flow. High resolution topographic GIS maps identified WSR-88D-defined locations of stratiform rains, rain showers, and multi-cellular thunderstorms comprising a mesoscale convective system. The evolution of the mesoscale convective system was concomitant with an overlapping region of surface equivalent potential temperature maximum and surface moisture flux divergence minimum (convergence maximum) situated in the Lower Snake River Plain and Southeast Highlands. The mesoscale system migrated up the Snake River Plain over a period of 6 hours accompanied by hourly rainfall rates of 1.00 to 2.00 inches near the cities of American Falls, Rockland, and Pocatello, Idaho. Based on the synoptic and mesoscale analyses, this manuscript proposes objective forecast guidance criteria (Maddox 1979) to assist operational forecasters in diagnosing future flash flood events in the region of study.

1. Introduction

Warm season convection is typically associated with precipitation minima in the Great Basin (Mock 1996) and specifically in the Snake River Plain of eastern Idaho (Andretta 1999).

However, climatological anomalies in monthly summer rainfall can occur in eastern Idaho dependent on the intrusion of the summer monsoon from the Desert Southwest United States into the Great Basin (Higgins et al. 1997; Higgins et al. 1999). In this case, a subtropical air mass permeated Utah and Idaho leading to flash flooding rains on 18 July 2004 in eastern Idaho. This poleward intrusion of the monsoon signaled several successive days of heavy rainfall in the region of study requiring the issuance of flash flood watches and warnings by operational meteorologists.

Analogue pattern matching is a didactic tool used by meteorologists and climatologists in forecasting the onset of non-severe (Andretta and Wojcik 2003) and severe (Carter and Keislar 2000; Andretta et al. 2004) meteorological conditions as a function of different indices. Multi-variable regression analyses (Andretta 2002; Andretta and Wojcik 2003) provide mathematical equations for predicting dependent variables based on the positive statistical correlations of related independent parameters. Maddox et al. (1980) identified several synoptic patterns based on climatology associated with the genesis of flash flooding in the western contiguous United States. In particular, this study documents positive correlations between the 18 July 2004 synoptic patterns and the Type III flash flood synoptic signatures illuminated by Maddox et al. (1980).

In response to several synoptic forcing mechanisms and mesoscale processes, scattered showers and thunderstorms developed in eastern Idaho during the early afternoon hours (1200 MDT or 1800 UTC) on 18 July 2004. The convection rapidly organized into a larger mesoscale convective system (MCS) (Houze et al. 1989; Nachamkin et al. 2000; Schumacher and Johnson 2005) which propagated at 15 to 20 knots from the Magic Valley to the Snake River Plain.

Characteristic of smaller MCSs that develop over complex topography (Knupp and Cotton 1987; Knupp et al. 1998a; Knupp et al. 1998b; Hedges 2004), the mesoscale system exhibited average brightness temperatures of -45 to -50 °C covering a total area of $\sim 1.0 \times 10^4 \text{ km}^2$ during a mobile 6 hour lifetime. During the formation and mature phases (2100 to 2200 UTC) of the MCS, anvil heights near the coldest (-55 to -60 °C) cloud tops extended to 45 kft MSL in the troposphere. Rainfalls totals of 1.00 to 2.00 inches per hour occurred in the varied terrain of the Lower Snake River Plain and Southeast Highlands, leading to flash flooding in several cities along the path of the MCS.

This study will provide detailed synoptic and mesoscale analyses of the flash flood event in accordance with similar forecasting methodologies (Doswell et al. 1996). Data sets employed in analyses will include NOAA GOES satellite and soundings, NOAA surface and upper air observations, MM5-ETA model output, and WSR-88D fields. Surface and WSR-88D parameters will be displayed on high resolution topographic GIS maps. The study will document objective guidance based on meteorological indices (Maddox 1979) to assist operational meteorologists in predicting future events in the region of study.

2. Background

a. Topography

1) Regional and State Domains

[Figure 1a](#) displays the regional domain for the Northwest United States and the outline of the state of Idaho. Idaho is land-locked on all sides and removed from the maritime influences of clouds and precipitation affecting coastal regions in the western United States. The northern and central parts of Idaho are characterized by terrain of variable symmetry and elevation. The southern part of the state is configured in a concave parabolic valley rising in slope from west to east across the domain. This principal topographic feature is the Snake River Plain. Located at

opposite ends of the expansive plain, the major population centers are Boise City in the western part followed by Pocatello and Rexburg in the eastern part of the state.

The state domain ([Figure 1b](#)) shows the county outlines for eastern Idaho with major bodies of water and cities for reference. This region borders Montana to the north, Wyoming to the east, Nevada to the southwest, and Utah to the south of the domain. The total area of the state domain encompasses a rectangle of $\sim 6.0 \times 10^4 \text{ km}^2$ and will be the region of focus for this study.

2) Local Domain (Eastern Idaho)

As [Figure 1c](#) indicates, there are several topographic features in eastern Idaho. The major feature is the Snake River Plain which has the symmetry of the right semicircle of a concave parabola. It spans $\sim 250 \text{ km}$ in length from the Magic Valley to the Upper Snake River Plain and is $\sim 100 \text{ km}$ wide. The plain rises smoothly in elevation in a southwest to northeast direction, from $z \sim 1.15$ to 1.35 km (all heights MSL) in the Magic Valley, to $z \sim 1.35$ to 1.50 km in the Lower Snake River Plain, to $z \sim 1.50$ to 1.65 km in the Upper Snake River Plain. [Figure 1c](#) illustrates this elevation gradation in the contour of a fishhook with the tail of the hook in the Magic Valley and the head of the hook curving from the Upper Snake River Plain to the Arco Desert. The Snake River Plain is surrounded by valley walls with higher terrain in the north, east, and south directions. This topographic variability leads to differences in meteorological conditions of atmospheric pressure, temperature, wind, cloudiness, and precipitation (Andretta 1999). For example, the northwest to southeast oriented valleys in the Central Mountains aid in terrain channeling of low-level wind flow; these gap flow winds empty from the Arco Desert into the Upper Snake River Plain (Stewart et al. 2002). Andretta (2005) documented a case of a nocturnal low-level jet and associated snowfall near the Central Mountain valley openings in the Arco Desert. Mesoscale convergence zones of wind and precipitation occur in the Snake River Plain under specific synoptic conditions prevalent in the fall and winter months (Andretta and Hazen 1998; Andretta 2002).

3) Local Domain (Southeast Idaho)

The local domain cited in this study ([Figure 1d](#)) is the area south of the Lower Snake River Plain in the complex terrain comprising a quadrilateral from between Aberdeen and Rockland to between Pocatello and McCammon. This area includes southwest Bingham county plus most of Power and Bannock counties. The highlands to the east and south of the Snake River Plain rise in elevation from $z \sim 1.55$ to $\sim 2.75 \text{ km}$. The following cities are highlighted in the manuscript. Located near the base of the parabola in the Lower Snake Plain, Aberdeen ($z \sim 1.35 \text{ km}$) is situated $\sim 10 \text{ km}$ southwest of the WSR-88D radar tower (yellow symbol) in very flat and exposed terrain in southwest Bingham county. The Snake River extends across northern Power county and empties into and out of American Falls Reservoir. The city of American Falls ($z \sim 1.37 \text{ km}$) lies just south of the reservoir in a relatively exposed region. Further south of these orographic features ([Figure 1d](#)), Rockland is located in an expansive north to south oriented valley ($z \sim 1.45$ to 1.55 km) in Power county and is bordered by higher terrain that rises sharply with the Sublett Range ($z \sim 1.95$ to 2.15 km) to the west and the Deep Creek Mountains ($z \sim 2.15$ to 2.45 km) to the east of the valley. The cities of Pocatello and Chubbuck ($z \sim 1.36 \text{ km}$), located in northern Bannock county, are nestled to the west of the Pocatello Mountains ($z \sim 1.75$ to 2.05 km) and to the east of the Bannock Range ($z \sim 1.55$ to 1.75 km). Situated in central Bannock county, McCammon ($z \sim 1.45 \text{ km}$) lies south of Pocatello at the nadir of a narrow

canyon west of the western slopes of the Portneuf Range ($z \sim 1.75$ to 2.05 km).

3. Data Sources

a. Terrain Data

Geographic Information Systems (GIS) digitized maps of terrain are available from the Geography Network for the contiguous United States and other geographical locations. Please see this online [database](#) for more information. These highly detailed GIS maps are utilized in this study to elucidate geographical and topographic references in eastern Idaho for the purposes of bolstering the mesoscale analysis.

b. Satellite Data

The National Oceanic and Atmospheric Administration (NOAA) operates a geostationary (GOES) satellite server which collects visible, infrared, and water vapor imagery over different geographical domains of the earth. Please see this [website](#) for more information. This study utilizes water vapor and infrared satellite imagery available from the NOAA GOES imager. The water vapor data (4 km resolution) were available at 1200 UTC 18 July 2004; infrared images (4 km resolution) were collected at 1800 UTC, 2100 UTC, 2200 UTC 18 July 2004, and 0000 UTC 19 July 2004.

c. Model Data

The University of Washington generates high resolution forecasts of the MM5 ensemble models twice daily (0000 and 1200 UTC) at various horizontal and vertical domains. These models include the MM5-ETA, MM5-GFS, and extended MM5-GFS simulations; a relatively new WRF-GFS ensemble model is also run at the university. These simulations are supported by the Northwest Regional Modeling Consortium. Please visit this [website](#) for details. This study employs the 36 km and 12 km grids of the MM5-ETA model initialized at 1200 UTC on 18 July 2004. The choice of the MM5-ETA model was based on agreeable model verification of several analyzed fields at different vertical levels including geopotential height, temperature, relative humidity, and wind. Other gridded model sources lacked sufficient detail of the above parameters compared to the MM5-ETA model and observations. The subgrid simulation of convection (Spencer and Stensrud 1998) and CAPE generation were resolved favorably in the MM5-ETA model. The 700 mb vertical velocity fields were not incorporated into the study because of excessively noisy numerical output.

d. Surface and Upper Air Observations

Skew-T/Log-P plots are available from the National Oceanic and Atmospheric Administration (NOAA) Storm Prediction Center (SPC) [archives](#). The radiosonde data at stations in Boise (City) Idaho (KBOI), Elko Nevada (KLKN), and Salt Lake City Utah (KSLC) initialized at 1200 UTC on 18 July 2004 were selected to monitor the antecedent kinematic environment for convective instability. Please see [Figure 1a](#) for the geographical locations of the radiosondes. In addition, objectively analyzed maps for 1200 UTC on 18 July 2004 at mandatory levels of 300

mb, 500 mb, 700 mb, 850 mb, and the surface were garnered from the NOAA SPC [archives](#).

e. Satellite Derived Soundings

NOAA GOES satellite atmospheric derived (experimental) soundings provide real-time observations of temperature, moisture, and stability in the [horizontal](#) and [vertical](#) dimensions.

Vertical sounding data are available every hour (including rolling 24 hour archives) for points across the contiguous United States, Canada, Mexico, adjacent oceans, and Hawaii. Please consult this [hyperlink](#) for more detailed information. In this study, sounding [data](#) were collected along the trajectory of the mesoscale convective system (MCS) near Pocatello (PIH) and Idaho Falls (IDA), Idaho ([Figure 1c](#)). The data were procured at 2100 UTC during high radar reflectivities and significant rainfall rates of the MCS. Unfortunately, other sampling times were not available during the flash flood event due to overcast cloud cover or data outages.

f. Radar Observations

This study uses Weather Surveillance Radar 1988 Doppler network (WSR-88D) data sets consisting of Level II base moments and Level III derived products available from the National Climatic Data Center (NCDC) online [repository](#). Radar data sets originate from the WSR-88D KSFY Radar Data Acquisition (RDA) tower located ~10 km northeast of Aberdeen or just north of American Falls Reservoir ([Figure 1d](#)). The temporal frequency of all radar data is every 5 minutes corresponding to operating precipitation mode VCP 11 and a reflectivity to rainfall (Z-R) convective relationship ($Z = 300 \cdot R^{1.4}$). The Echo Tops (ET) product defines the highest vertical extent of the cloud tops indicative of rising or sinking motions in the mesoscale convective system. Vertically Integrated Liquid (VIL) integrates the water content in a 2.2 x 2.2 nm column depth for identification of heavy rainfall in convective storms. Composite Reflectivity (CR), defined as the maximum reflectivity in a volume scan above a given point, measures the spatial distribution and intensity of radar echoes (Andretta and Hazen 1998; Andretta 2002). One Hourly Precipitation (OHP) totals are collected each volume scan in a 1.1 x 1.1 nm grid to estimate rainfall intensity rates for flash flooding (Baeck and Smith 1998; Brooks and Stensrud 2000; Warner et al. 2000). Vertical Wind Profiles (VWP) of the atmosphere provide time series of environmental wind flow and shear that influenced the mesoscale convective system.

g. Surface Observations

The NOAA Forecast Systems Laboratory (FSL) generates the Mesoscale Analysis and Prediction System (MAPS) Surface Assimilation System (MSAS) hourly real-time data sets of analyzed and derived meteorological grids. Please see this [hyperlink](#) for more information. This study uses two key meteorological fields: surface equivalent potential temperature (θ_e)

(Richmond and Springer 2004) and surface moisture flux divergence ($\nabla \cdot (q \mathbf{V}_h)$) (Junker et al. 1999) to investigate the kinematic environment of the convection that developed in the afternoon hours on 18 July 2004. Equivalent potential temperature identifies buoyant air parcels resulting from the process of moist adiabatic ascent (expansion), complete latent heat of condensation release, and dry adiabatic descent (compression) to a standard pressure of 1000 mb (Bolton 1980). Since θ_e increases with increasing temperature and moisture content, a θ_e maximum or

ridge in the atmosphere delineates an area of greatest warm air and moisture advection. Positive (negative) values of moisture flux divergence (convergence) identify moisture outflow (inflow) across a horizontal (h) (x, y) plane. This horizontal plane is defined as the surface (Banacos and Schultz 2005). Despite some limitations (Banacos and Schultz 2005), surface moisture flux convergence can be operationally useful as a diagnostic indicator of convective initiation.

Accordingly, given adequate atmospheric instability, correlated *positive* θ_e and *negative* $\nabla \cdot (q \mathbf{V}_h)$ values depict lift of a source of warm and moist air parcels above the level of free convection (LFC) resulting in convective precipitation.

4. Upper Air Analysis: Satellite, Surface, and Upper Air Observations

a. Water Vapor Imagery

At 1200 UTC 18 July 2004, the NOAA GOES imager on the water vapor channel ([Figure 2](#)) depicted a closed 400 mb low pressure center (131W, 45N) along the Washington and Oregon coasts. A second and smaller circulation was evident over northeast Nevada (west of Salt Lake City, Utah) with relatively deep layer 300 to 500 mb moisture (50 to 60 %) across Idaho. The Nevada circulation provided moisture transport over Utah and Idaho in connection with the poleward migration of monsoonal air from the southwest United States.

b. Mandatory Level Charts

The NOAA SPC objectively analyzed maps for 1200 UTC 18 July 2004 are displayed at 300 mb ([Figure 3a](#)), 500 mb ([Figure 3b](#)), 700 mb ([Figure 3c](#)), 850 mb ([Figure 3d](#)), and the surface ([Figure 3e](#)). A longwave ridge-trough pattern at 300 and 500 mb was in place across the coterminous United States. The 300 mb chart indicated a closed upper-level low pressure system off the Oregon coast with a meridionally oriented jet (70 to 80 knots) along the Washington and Oregon coasts. Upper-flow became more variable and lighter over Utah and Colorado. A moderate amplitude 300 mb ridge axis ([Figure 3a](#)) was situated along the spine of the Rocky Mountains with one center of the anticyclonic gyre over western New Mexico and a second center west of southern Texas. There was 300 mb wind flow between 10 and 15 knots across most of Idaho, Wyoming, and Utah; weak 300 mb divergence was located over a small part of eastern Idaho. The 500 mb temperatures ([Figure 3b](#)) near the maritime closed (5640 m) low were -14 to -16 °C and increased in magnitude further inland in a range from -6 to -9 °C over Idaho, Wyoming, and Utah. Upper air analysis depicted a 500 mb shortwave trough over northeast Nevada.

At the lower levels, a 700 shortwave trough of low pressure ([Figure 3c](#)) was evident over northern Nevada and northern Utah. The 700 mb dry bulb temperatures ([Figure 3c](#)) were 10 to 13 °C over Idaho and Utah with a 5 °C dewpoint temperature contour (local maximum) in the vicinity of the 700 mb wave. The 850 mb chart ([Figure 3d](#)) showed dry bulb temperatures of 20 to 24 °C. The 850 mb dewpoint isotherms of 10 to 12 °C were evident across Idaho; a local maximum of 12 °C covered an area along the Nevada-Utah border and near the Great Salt Lake, Utah. Hence, there was a broad southwest flow from 300 to 700 mb across the western United

States with a larger height gradient (weaker wind field) closer to the upper-level ridge axis. The mean southwest flow aloft and shortwave troughs at the lower to mid-levels over northern Nevada aided in the transport of warm air and moisture across Utah and Idaho in the early morning hours. This pattern was reflected in the relatively small (2 to 11 °F) surface dewpoint depressions ([Figure 3e](#)) in the region of study. Light (5 to 10 knots) southwest to southeast surface wind speeds occurred over eastern Idaho. In sum, these synoptic indicators were very similar to the climatological Type III flash flood synoptic signatures for the western United States described by Maddox et al. (1980).

c. Skew-T/Log-P Diagrams

The Skew-T/Log-P diagrams for Boise (City) Idaho (KBOI), Elko Nevada (KLKN), and Salt Lake City Utah (KSLC) are illustrated at 1200 UTC 18 July 2004 in [Figures 4a](#), [4b](#), and [4c](#), respectively. All of the soundings recorded the presence of the monsoonal air mass with Precipitable Water (PW) > 1.20 inches, K Index (K) ~ 30, low lifting condensation level (LCL) heights (~ 685 mb), and drier sub-cloud regions forming the inverted "V" thermal structure in the planetary boundary layer of the profiles. There was a shallow inversion in the lowest layer near the ground on each Skew-T/Log-P diagram. The depth of the warm cloud layer, defined as the vertical distance from the LCL height along a moist adiabat to the 0 °C isotherm on the Skew-T/Log-P plot, was ~ 1.5 km at each sounding location.

The air mass over western Idaho at KBOI was very moist with PW = 1.41 inches and K = 34. The dry bulb temperature and dewpoint temperature profiles were saturated above 600 mb according to the moist adiabatic lapse rate. Light easterly winds below 700 mb backed to a northerly flow (cold air advection) above the planetary boundary layer. Stability parameters were modest with Convective Available Potential Energy (CAPE) ~ 150 J kg⁻¹ and Lifted Index (LI) ~ -1. Further downstream, the Elko sounding was more unstable (CAPE ~ 900 J kg⁻¹; LI ~ -2) and contained slightly less moisture depth between 300 and 600 mb as compared to the KBOI sounding. Note the passage of the 700 mb trough in the KLKN vertical wind profile as winds veered aloft through the planetary boundary layer. The sounding at Salt Lake City (south of the local domain in eastern Idaho: [Figure 1c](#)) was very unstable with CAPE ~ 1300 J kg⁻¹ and LI ~ -3. The KSLC radiosonde was clearly the most unstable of the three soundings. Low-level southeast winds of 5 to 10 knots veered slowly with height to southwest flow of 15 to 25 knots up to ~500 mb. Based on these trends and advection of the upstream flow, the air masses sampled at KLKN and KSLC in the morning hours were precursors for afternoon convection in eastern Idaho.

Precipitation efficiency is defined as the ratio of the mass of water falling as precipitation to the influx of water vapor mass into a cloud (Doswell et al. 1996). This quantity is directly related to environmental relative humidity and cloud precipitable water. The shape of the CAPE on a Skew-T/Log-P diagram is an important factor in assessing heavy rainfall and potential flash flooding. Skinny CAPE in sufficient amounts is an essential ingredient for heavy liquid precipitation forming in a deep warm cloud layer (Doswell et al. 1996). The modest positive vertical motions in a cloud allow ascent of condensation nuclei in the warm layer supporting peak precipitation efficiency of liquid water droplets. By contrast, fat CAPE leads to intense vertical updrafts well above the warm cloud layer promoting the development of frozen hydrometeors (e.g., hail and ice pellets). Hence, fat CAPE mitigates precipitation efficiency of

liquid water droplets. These differences will be explained in the NOAA GOES soundings germane to the mesoscale analysis of the MCS and heavy rainfall in eastern Idaho.

5. Synoptic Analysis: MM5-ETA Model Forecast

a. Antecedent Environment: 1200 UTC 18 July 2004

Figures 5a and 5b show the 300 mb and 500 mb geopotential height, temperature, and wind patterns during the early morning hours before the flash flood event. There was a closed cool (-40 to -44 °C) core 300 mb low pressure center off the Oregon coast with a south to southwest flow across Idaho, Nevada, and Utah. These initial positions of the 300 and 500 mb low pressure centers were consistent with the satellite observations (Figure 2). The upper-level height gradient weakened considerably from the coastal regions of Washington and Oregon to further inland across Idaho. The 300 mb chart in Figure 5c showed a 60 to 70 knots wind speed maximum moving south to north along the Oregon coast and matched up favorably with the upper air observations (Figure 3a). Wind speeds decreased in magnitude further inland and were 10 to 20 knots across southern Idaho. A 500 mb trough (5852 m) of low pressure and attendant region of positive absolute vorticity (Figure 5d) were located from west-central Idaho to northern Nevada.

The 700 mb pattern in Figure 6a identified a shortwave trough over northeast Nevada in agreement with the location in the Elko Nevada (KLKN) sounding (Figure 4b). The model also depicted a closed 700 mb low pressure (3134 m) center over central Idaho. The 850 mb pattern (Figure 6b) revealed warm dry bulb temperatures of 22 to 24 °C and breezy south to southeast winds of 10 to 20 knots across eastern Idaho and northern Utah. Thus, there was warm air advection occurring in the MM5-ETA model within the planetary boundary layer over eastern Idaho downstream of the 700 mb trough. The surface chart (Figure 6c) divulged a 1004 mb surface low over central Idaho with a thermal ridge nosing meridionally from northern Utah to the Idaho-Wyoming border. Convective instability was very high regionally (Figure 6d), with model CAPE values of 1000 to 1400 J·kg⁻¹ across eastern Oregon, northern Nevada, and parts of western Idaho. By comparison, in the local domain, CAPE values in the Snake River Plain of Idaho were between 150 and 400 J·kg⁻¹.

The relative humidity charts are displayed at 500 mb (Figure 7a), 700 mb (Figure 7b), and 850 mb (Figure 7c). Deep moisture was present at 500 mb with values between 85 and 95 % at 500 mb across most of eastern Idaho and northern Nevada. At the lower levels below 500 mb, relative humidities were 70 to 80 % at 700 mb and 850 mb in the same region, indicative of the drier air (e.g., inverted "V" thermal structure) depicted in the 1200 UTC KLKN and KSLC soundings. No 3-hourly precipitation chart was available at this time step.

In sum, the antecedent conditions were favorable for convective precipitation to develop across eastern Idaho in the afternoon hours. These synoptic indicators at 1200 UTC resembled the climatological Type III flash flood synoptic signatures discussed by Maddox et al. (1980).

b. Pre-MCS Stage: 1800 UTC 18 July 2004

The upper-level low pressure systems at both 300 mb ([Figure 8a](#)) and 500 mb ([Figure 8b](#)) indicated little downstream motion and were stacked vertically in the atmosphere. Likewise, the upper-level anticyclones at 300 mb (9730 m) and at 500 mb (5927 m) remained anchored across the southwest United States. The 300 mb temperatures of -40 to -44 °C were collocated with the low pressure center. The 300 mb wind speed maximum (jet) ([Figure 8c](#)) persisted along the Washington and Oregon coasts; south winds of 15 to 20 knots continued across eastern Idaho. At the mid-levels ([Figure 8d](#)), the 500 mb trough of low pressure was present over northeast Nevada with a well-defined band of positive absolute vorticity extending from central Idaho to northeast Nevada. Note the extension of this vorticity pattern into the Upper Snake River Plain of eastern Idaho ([Figure 1c](#)).

The 700 mb wind flow in [Figure 9a](#) was south to southeast at 15 to 20 knots with a trough near the Oregon-Idaho border. At 850 mb ([Figure 9b](#)), the flow was lighter with winds variable in direction at 10 knots. As [Figure 9c](#) demonstrates, the horizontal surface pressure gradient remained very weak across Idaho. The model CAPE values ([Figure 9d](#)) increased markedly from 3 hours earlier across all of Idaho with values between 200 and 900 J·kg⁻¹ at 1800 UTC. A CAPE maximum of 1500 to 1700 J·kg⁻¹ was located over northern Utah near the Great Salt Lake. This unstable air mass advected into eastern Idaho during the afternoon hours.

The relative humidity charts are displayed at 500 mb ([Figure 10a](#)), 700 mb ([Figure 10b](#)), and 850 mb ([Figure 10c](#)). There were high (80 to 90 %) relative humidities at 500 and 700 mb with lesser amounts (60 to 70 %) at 850 mb across eastern Idaho. The moisture advection was crucial in moistening the drier air in the lower levels below 685 mb in the 1200 UTC KLKN and KSLC soundings. The 3-hourly precipitation map ([Figure 10d](#)) indicated rainfall (0.01 to 0.08 inches) overspreading the western half of Idaho ([Figure 1c](#)).

c. MCS Formation Stage: 2100 UTC 18 July 2004

By the mid-afternoon hours as the heavy rainfall commenced over parts of eastern Idaho, the coastal upper-level low pressure centers at 300 mb ([Figure 11a](#)) and 500 mb ([Figure 11b](#)) moved slightly north in latitude from prior positions. A moderate amplitude ridge at the 300 and 500 mb levels persisted over the interior Rocky Mountain states. From 1800 to 2100 UTC, there was little change in the height or temperature fields of the mid and upper-level cyclones, suggesting a barotropic state in the MM5-ETA simulation. The 300 mb southerly flow ([Figure 11c](#)) was still very strong (60 to 70 knots) along the Oregon coast and weaker (10 to 20 knots) across eastern Idaho. A 5880 m height contour ([Figure 11d](#)) delineated a 500 mb trough over northeast Nevada with a band of positive absolute vorticity near the Magic Valley of eastern Idaho and along the Idaho-Utah border.

There was a 700 mb trough ([Figure 12a](#)) over western Idaho with the 850 trough ([Figure 12b](#)) over central Idaho. The wind flow at 850 mb ([Figure 12b](#)) and the surface ([Figure 12c](#)) depicted a light southerly horizontal gradient. Convective instability ([Figure 12d](#)) was widespread in the mid-afternoon hours. The CAPE values increased to 1100 to 1600 J·kg⁻¹ across the Snake River Plain with the highest values (1600 J·kg⁻¹) in the Upper Snake River Plain of eastern Idaho. A second region of comparably high CAPE values extended from the Lower Snake River Plain of eastern Idaho to northern Utah.

Relative humidity charts at 500 mb ([Figure 13a](#)), 700 mb ([Figure 13b](#)), and 850 mb ([Figure 13c](#)) indicated values between 75 and 90 % in eastern Idaho as the upstream trough contributed to effective moisture transport into the local domain. The 3-hourly precipitation map ([Figure 13d](#)) indicated rainfall overspreading the central Mountains and Snake River Plain of Idaho with amounts generally between 0.08 to 0.16 inches. There was a local precipitation maximum of 0.16 to 0.32 inches situated in the complex terrain south of the Lower Snake River Plain ([Figure 1d](#)).

d. Post-MCS Stage: 0000 UTC 19 July 2004

As Figures [14a](#) and [14b](#) indicate, the 300 and 500 mb low pressure centers continued a slow northward motion parallel to the Washington-Oregon coastline. The axis of 300 mb wind speeds ([Figure 14c](#)) was 60 to 70 knots and followed this progression. There was a region of 300 mb wind speeds of 15 to 20 knots ([Figure 14c](#)) across eastern Idaho. The 500 mb trough of low pressure in [Figure 14d](#) shifted east into northwest Utah with a band of northwest to southeast oriented positive absolute vorticity from central Idaho to northern Utah. A segment of positive absolute vorticity also extended into the Snake River Plain of eastern Idaho.

The 700 mb trough ([Figure 15a](#)) was over southern Idaho just west of the Magic Valley ([Figure 1c](#)). Light upvalley flow persisted at 850 mb and the surface across the Snake River Plain as depicted in Figures [15b](#) and [15c](#), respectively. Moderate to high convective instability was present in the state and local domains. The MM5-ETA CAPE chart ([Figure 15d](#)) revealed values between 400 and 1200 J·kg⁻¹ across most of southern Idaho, northern Nevada, and northern Utah. A local CAPE maximum of 1600 to 2100 J·kg⁻¹ was present across the Lower and Upper Snake River Plains of eastern Idaho.

The relative humidity charts at 500 mb ([Figure 16a](#)), 700 mb ([Figure 16b](#)), and 850 mb ([Figure 16c](#)) indicated values between 80 and 95 % across eastern Idaho suggesting deep layer moisture advection. The 3-hourly precipitation map ([Figure 16d](#)) indicated rainfall overspreading the central Mountains and Snake River Plain with amounts generally between 0.16 and 0.32 inches. A local precipitation maximum of 0.32 to 0.64 inches was situated in the complex terrain bordering the Lower Snake River Plain and Southeast Highlands.

6. Mesoscale Analysis: Satellite, Surface, and Radar Observations

a. Pre-MCS Stage: 1800 UTC 18 July 2004

The NOAA GOES infrared satellite imagery at 1800 UTC in [Figure 17a](#) indicated cold (-25 to -35 °C) cloud tops across southern Idaho with much colder (-40 to -50 °C) tops near the Idaho-Montana border. National Weather Service (NWS) METAR observations showed moist (55 to 65 °F) surface dewpoint temperatures indicative of the monsoonal air mass across the state domain. Light (~5 knots) northeast winds prevailed at KIDA (Idaho Falls) and near Aberdeen at KPIH (Pocatello Airport). The KSFX WSR-88D wind profiler between 1740 and 1829 UTC ([Figure 17b](#)) indicated northeast winds (5 to 10 knots) within 2 kft of the ground during the late morning and early afternoon hours related to drainage flow in the Snake River Plain. Wind

speeds of 10 to 20 knots veered with height from a south to southwest direction between 8 and 23 kft (all heights MSL). The 1800 UTC mesoscale analysis of MSAS θ_e (surface equivalent potential temperature) (Figure 17c) showed a ridge nosing upvalley with the topography from the Magic Valley (347 °K) to the Upper Snake River Plain (340 °K). A northeast to southwest oriented trough of θ_e was located across the Eastern and Southeast Highlands. Of noteworthy importance, the MSAS $\nabla \cdot (q \mathbf{V}_h)$ (surface moisture flux divergence) minimum (-6 to -18 g·12 hr kg⁻¹) illustrated in Figure 17d was situated in the Southeast Highlands centered near Malad City and spatially disjointed from the MSAS θ_e maximum.

As Figure 18a shows, the echo tops from the KSFx WSR-88D at 1804 UTC were 15 to 35 kft over the Central Mountains and Upper Snake River Plain. However, cloud tops were higher (30 to 40 kft) in the highlands south of the Magic Valley. The vertically integrated liquid values at 1804 UTC (Figure 18b) across the Magic Valley were between 10 and 15 kg·m⁻² near Albion. Likewise, the composite reflectivity chart at 1804 UTC (Figure 18c) illustrated scattered strong convective cells (40 to 50 dBZ) developing near the θ_e ridge axis. Radar echoes also formed across the higher terrain north of the Upper Snake River Plain with reflectivities of 20 to 40 dBZ. This feature was associated with the 500 mb positive vorticity area (Figure 8d) mentioned earlier. Precipitation developed in the Central Mountains in line with the MM5-ETA trend (Figure 10d). Hourly precipitation amounts at 1804 UTC (Figure 18d) were light (0.05 to 0.20 inches) across most of eastern Idaho with 0.20 to 0.50 inches between Mud Lake and Roberts. However, there was no flash flooding reported by weather spotters in these locations.

b. MCS Formation Stage: 2100 UTC 18 July 2004

The NOAA GOES infrared imagery at 2100 UTC in Figure 19a indicated a large area of cold cloud tops in the Magic Valley and Lower Snake River Plain corresponding to brightness temperatures of -40 to -55 °C with the coldest (-55 °C) tops between Aberdeen and Rockland.

As explained in the next paragraph, this feature coincided with the development of a mesoscale convective system (MCS). The KSFx WSR-88D wind profiler between 2039 and 2129 UTC (Figure 19b) showed winds veering with time at the surface from a northeast to southeast direction with a homogeneous southwest flow of 15 to 20 knots above 7 kft. At 2100 UTC, there was an intersection of the MSAS surface equivalent potential temperature (Figure 19c) maximum and MSAS surface moisture flux convergence (Figure 19d) minimum across north-central Bannock and Power counties. In particular, positive θ_e values above 345 °K intersected negative $\nabla \cdot (q \mathbf{V}_h)$ values below -9 g·12 hr kg⁻¹ in the local domain between American Falls and Pocatello (Figure 1d). Thus, a source of warm and moist air was lifted in the unstable atmosphere producing convective precipitation.

Echo tops at 2029 UTC (Figure 20a) were 35 to 45 kft from Rockland to Malad City. A trailing area of lower cloud tops (20 to 30 kft) was situated from Minidoka to Malta. The echo tops of 45 kft approximated the altitude of the coldest cloud tops and thunderstorm anvils. The values for vertically integrated liquid at the same time (Figure 20b) were between 25 and 40 kg·m⁻² from Rockland to Malad City. As noted by McAnelly et al. (1997), radar-based VIL can be used

to distinguish between stratiform and convective precipitation; numerical VIL values above $2.5 \text{ kg}\cdot\text{m}^{-2}$ define the convective elements. The map of composite reflectivity from the KSFY WSR-88D at 2029 UTC is displayed in [Figure 20c](#). A large area of precipitation covered the Lower Snake River Plain forming a mesoscale convective system (Knupp and Cotton 1987; Houze et al. 1989; Knupp et al. 1998a; Knupp et al. 1998b). The MCS spanned an area $\sim 1.0 \times 10^4 \text{ km}^2$, structurally consisting of a uniform circular region of light to moderate (25 to 35 dBZ) precipitation surrounding a linear band of heavy (45 to 55 dBZ) precipitation extending from Rockland to Malad City. The light to moderate precipitation shield coinciding with the lower echo tops was comprised of stratiform rains and rain showers based on VIL thresholds (McAnelly et al. 1997). The heavy precipitation region was composed of intense multi-cellular thunderstorms exhibiting minimal tilt in the low wind shear environment with deep convective cores (45 to 55 dBZ) in the lowest layer (5 to 24 kft) of the base reflectivity volume scans (not shown). The intensity and character of the MCS precipitation regime as defined by the WSR-88D were consistent with reports from NWS surface observations ([Figure 19a](#)). The MCS moved downstream (forward propagation) with the mean southwest flow (Schumacher and Johnson 2005). In addition to mesoscale processes, the low-level southwest flow promoted orographic lift of moist air along the western (windward) slopes of the Deep Creek Mountains ([Figure 1d](#)). This orographic signature was evident in the linear orientation of the thunderstorms and higher reflectivities relative to the topographic ridge line. Regarding obstacle flow, the Froude number [$F = u(Nh)^{-1/2}$] (Levinson and Banta 1995) at $z = 2.30 \text{ km}$ (average elevation of the Deep Creek Mountains) was estimated using the 1200 UTC KSLC sounding and KSFY WSR-88D VWP products. In this equation, u is the cross-barrier wind speed and N is the square root of the Brunt-Vaisala frequency over the mountain depth, h . The assigned values of $u = 15 \text{ m}\cdot\text{s}^{-1}$, $N = 0.015 \text{ s}^{-1}$, and $h = 776 \text{ m}$ yielded $F = 1.29$. This Froude number corresponded to unblocked flow with ascent of precipitation upstream and along the barrier in an unstable regime. Rainfall rates (OHP) at 2104 UTC ([Figure 20d](#)) were conducive to flash flooding with values of 1.00 to 1.50 inches per hour in the Rockland and Arbon Valleys.

The NOAA GOES vertical soundings at 2100 UTC for Pocatello ([Figure 21a](#)) and Idaho Falls ([Figure 21b](#)) divulged PW ~ 1.50 inches with CAPE values between 1900 and 2200 $\text{J}\cdot\text{kg}^{-1}$. Both profiles exhibited skinny CAPE configurations (pink area) from $\sim 710 \text{ mb}$ to $\sim 150 \text{ mb}$. These CAPE observations were in close agreement with the MM5-ETA forecast ([Figure 12d](#)). The LCL heights were $\sim 730 \text{ mb}$ in both soundings or $(730 - 685) \text{ mb} = 45 \text{ mb}$ lower in the atmosphere versus the 1200 UTC KLKN and KSLC environments. Likewise, warm cloud layers in the 2100 UTC profilers were relatively deep ($\sim 3.1 \text{ km}$) or $(3.1 - 1.5) \text{ km} = 1.6 \text{ km}$ thicker versus the 1200 UTC KLKN and KSLC environments. These thermodynamic anomalies were indicative of effective moisture transport from the upstream 500 and 700 mb shortwave troughs. Thus, the NOAA GOES profilers near Pocatello and Idaho Falls were representative of an air mass conducive to heavy rainfall and potential flash flooding. The KSFY WSR-88D OHP values were nearly equal to the NOAA GOES PW values with high precipitation efficiency of liquid water droplets from the clouds in the MCS.

c. MCS Mature Stage: 2200 UTC 18 July 2004

As indicated in the NOAA GOES infrared imagery at 2200 UTC ([Figure 22a](#)), the MCS moved slowly (~ 15 knots) up the Snake River Plain with very cold cloud tops of -50 to -60°C near the center of the convective system between Aberdeen and Blackfoot. This marked the peak

intensity of the MCS in eastern Idaho. Surface reports indicated heavy rainfall from thunderstorms at Pocatello, Chubbuck, Inkom, and McCammon. The KSFx WSR-88D wind profiler time series changed marginally between 2134 and 2223 UTC (Figure 22b) with southeast winds ~ 10 knots at the surface and a deep layer of southwest flow (15 to 20 knots) devoid of wind directional shear above 7 kft. Moisture and warm air advection at 2200 UTC persisted across Bannock county with MSAS θ_e maximum of 359 to 363 °K (Figure 22c) centered near Pocatello. This region of θ_e maximum was collocated with a similar area of MSAS $\nabla \cdot (q \mathbf{V}_h)$ minimum (-18 to -27 g·12 hr·kg⁻¹) centered near McCammon, as illustrated in Figure 22d.

Echo tops at 2149 UTC (Figure 23a) were 35 to 45 kft across the Pocatello and Chubbuck areas indicative of strong positive vertical motions through a deep warm cloud layer of ~ 3.1 km. The echo tops of 45 kft approximated the altitude of the coldest cloud tops and thunderstorm anvils. The values for vertically integrated liquid at 2149 UTC (Figure 23b) were very high (40 to 55 kg·m⁻²) in these locations. The MCS covered an area ~1.0 x 10⁴ km² in the Lower Snake River Plain and Southeast Highlands, as indicated in Figure 23c. The radar structure of stratiform and convective elements in the MCS described at 2029 UTC was also conspicuous at 2149 UTC. The region of stratiform precipitation persisted possibly as older convective cells dissipated within the MCS (Houze et al. 1989). As the system migrated downstream, the peak composite reflectivity intensities (50 to 60 dBZ) were occurring from Pocatello to McCammon. Orographic ascent of rich θ_e air in the mean southwest flow was a factor in producing heavy rainfall along the western slopes of the Pocatello Mountains and Portneuf Range (Figure 1d). The Froude number (Levinson and Banta 1995) at z = 1.90 km (average elevation of the Pocatello Mountains and Portneuf Range) was estimated using similar data sources documented in the previous section. The values of u = 13 m·s⁻¹, N = 0.015 s⁻¹, and h = 680 m yielded F = 1.27 or unblocked flow with ascent of precipitation upstream and along the barrier in an unstable regime. The hourly precipitation chart from the KSFx WSR-88D at 2203 UTC (Figure 23d) showed 1.00 to 2.00 inches of rainfall in an area from between American Falls to Rockland to between Pocatello and Inkom. There was a similar precipitation maximum estimated by the radar from McCammon to Malad City. Based on the 2100 UTC NOAA GOES precipitable water output, these rainfall estimates suggested high precipitation efficiency of liquid water droplets from the clouds in the MCS.

d. Post-MCS Stage: 0000 UTC 19 July 2004

The NOAA GOES infrared imagery at 0000 UTC (Figure 24a) indicated that the MCS progressed slowly from the Lower Snake River Plain to the Upper Snake River Plain with the coldest (-50 to -60 °C) cloud tops in the Upper Snake River Plain (near Idaho Falls) and over the Eastern Highlands (near Driggs). The KSFx WSR-88D wind profiler between 2308 and 2358 UTC (Figure 24b) exhibited a unidirectional profile of southwest flow of 10 to 20 knots from the surface to 30 kft. The MSAS surface equivalent potential temperature (Figure 24c) maximum and MSAS surface moisture flux divergence (Figure 24d) minimum at 0000 UTC completely decoupled over the local domain. However, θ_e maximum of 350 to 352 °K remained across the Southeast Highlands. In addition to this anomaly, there were small areas of negative $\nabla \cdot (q \mathbf{V}_h)$

values (-2 to -4 g·12 hr·kg⁻¹) denoting surface moisture flux convergence in the Magic Valley (near Declo) and Upper Snake River Plain (near Ririe). The forcing mechanism for the cooling cloud tops in the MCS across the Eastern Highlands remains unclear. Nonetheless, the source of warm and moist air present between 1800 and 2200 UTC across the Lower Snake River Plain and Southeast Highlands dissipated in coverage and intensity. This occurrence signaled an end to the heavy rainfall event in Power and Bannock counties.

Consistent with the warming brightness temperatures in the infrared satellite imagery, echo tops at 2358 UTC ([Figure 25a](#)) decreased in height (15 to 25 kft) versus 2200 UTC across northern Bannock county in Pocatello and Chubbuck. The values for vertically integrated liquid at 2358 UTC in [Figure 25b](#) similarly diminished to 5 kg·m⁻² in this region. However, higher cloud tops and VILs developed in the Arco Desert. The KSFx WSR-88D chart for composite reflectivity at 2358 UTC is displayed in [Figure 25c](#). Isolated strong convection (thunderstorms) formed east of Arco with peak composite reflectivity intensities of 50 to 60 dBZ. As the thunderstorms in the MCS weakened over the Snake River Plain, a region of stratiform rains and rain showers (15 to 30 dBZ) developed from Rexburg to Blackfoot. The hourly precipitation chart from the KSFx WSR-88D at 2358 UTC ([Figure 25d](#)) showed rainfall amounts between 0.50 and 1.00 inches over the Arco Desert with much lighter amounts (0.01 to 0.15 inches) in the Snake River Plain.

7. Operational Preparedness and Spotter Reports

A flash flood watch was issued at 1015 AM MDT (1615 UTC) on 18 July 2004 by staff meteorologists at the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) office in Pocatello/Idaho Falls, Idaho. This watch had a 5 hour lead time prior to the first reports of flash flooding in Power and Bannock counties. In addition, several timely flash flood warnings were issued by meteorologists during the afternoon hours for American Falls, Rockland, and Pocatello.

The local storm reports from trained weather spotters for the flash flood event are displayed in [Table 1](#). Many of these reports of heavy rainfall at American Falls, Rockland, and Pocatello coincided with precipitation estimates from the KSFx WSR-88D. Although the MM5-ETA model underestimated the observed precipitation totals by a factor of ~2.0 for the event, there was excellent *qualitative* agreement between both data sets in the spatial distributions of the heaviest rainfall. The main hydrological impact of this event was urban as flooding occurred along the major highway passing through Rockland and along several streets in Pocatello. Area watersheds were not adversely impacted by the heavy rains. Moreover, flooding did not occur in scarred topography originating from wildfires or prescribed burns. No climatological studies were available in the scientific literature for comparison demonstrating positive statistical correlations between flooding and scarred terrain in eastern Idaho.

8. Objective Forecast Guidance

Objective forecast guidance based on mesoscale factors for the flash flood episode on 18 July

2004 is indicated in [Table 2](#). The table is divided into level and layer parameters. Level parameters include MSAS equivalent potential temperature and surface moisture flux divergence data; layer parameters include atmospheric sounding precipitable water, NOAA GOES CAPE, and KSRX WSR-88D wind profiler data. The critical thresholds for each index were selected to represent the convective environment before (1200 UTC) and during (1800 to 2200 UTC) the mesoscale convective system's trajectory over the Magic Valley and Lower Snake River Plain of eastern Idaho. As discussed by Maddox (1979), this type of objective forecast guidance can be used by operational forecasters to diagnose future flash flood episodes in the region of study.

9. Conclusions

This study analyzed synoptic and mesoscale conditions of a flash flood episode which occurred on 18 July 2004 in eastern Idaho. The climatological Type III synoptic pattern for the western United States documented by Maddox et al. (1980) was in place during the heavy rainfall event.

Observed soundings in the region of study contained low LCL heights ($z \sim 685$ mb), deep warm cloud layers, precipitable water values between 1.20 and 1.60 inches, and skinny CAPEs between 1300 and 2200 $\text{J}\cdot\text{kg}^{-1}$. There was low wind speed shear in the moist layer and small wind directional shear below $z \sim 7$ kft (2.13 km) MSL in the drier sub-cloud layer. Upper tropospheric flow above 400 mb was weak.

The MM5-ETA model was instrumental in forecasting the initial positions and downstream motions of the 500 and 700 mb shortwave troughs over northeast Nevada and western Idaho.

These minor waves facilitated effective moisture transport in the planetary boundary layer across eastern Idaho. The model realistically simulated the temporal development of convective instability preceding and during the precipitation event. Although the MM5-ETA model underestimated the magnitude of the precipitation amounts by ~ 2.0 in the region of study, it correctly resolved the locations of the heaviest rainfall in the Lower Snake River Plain where flash flooding occurred.

Convection developed during the early afternoon hours (1200 MDT or 1800 UTC) and propagated slowly downstream in the mean southwest flow. High resolution topographic GIS maps identified WSR-88D-defined locations of stratiform rains, rain showers, and multi-cellular thunderstorms comprising a mesoscale convective system. The evolution of the MCS was concomitant with an overlapping region of surface equivalent potential temperature maximum and surface moisture flux divergence minimum (convergence maximum) situated in the Lower Snake River Plain and Southeast Highlands. The MCS structure consisted of a large circular region of stratiform rains and rain showers with an embedded linear band of multi-cellular thunderstorms. As measured by radar reflectivity and the Froude number, topography was an integral factor -- orographic upslope flow contributed to heavy precipitation along the western (windward) slopes of the Deep Creek Mountains, Pocatello Mountains, and Portneuf Range. The precipitation spatially extended across these barriers in unblocked flow. The mesoscale system migrated up the Snake River Plain and lasted about 6 hours. During the formation and mature phases (2100 to 2200 UTC) of the MCS, anvil heights near the coldest (-55 to -60 $^{\circ}\text{C}$) cloud tops extended to 45 kft MSL in the troposphere. Inferred precipitation efficiency of liquid water droplets through deep warm cloud layers promoted hourly rainfall rates of 1.00 to 2.00

inches near the cities of American Falls, Rockland, and Pocatello, Idaho.

A flash flood watch and several flash flood warnings were issued by staff meteorologists at the NOAA NWS office in Pocatello/Idaho Falls, Idaho. The main hydrological impact of this event was urban as flooding occurred along the major highway passing through Rockland and along several streets in Pocatello. Based on the synoptic and mesoscale analyses, this manuscript proposed objective forecast guidance criteria (Maddox 1979) consisting of level and layer indices to assist operational forecasters in diagnosing future flash flood events in the region of study.

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Mr. Andretta has lead authored two journal papers on the Snake River Plain Convergence Zone (SPCZ) of eastern Idaho. He has also lead authored studies on harmonic analysis of precipitation time series in Idaho and low-level wind speed maximum in the Arco Desert of eastern Idaho.

Other coauthored studies include heavy snowfall synoptic patterns and tornado climatology of eastern Idaho. His interests include boundary layer meteorology in complex terrain, fog physics, mesoscale precipitation processes, snowfall climatology, and tornado climatology. Mr. Andretta has created several major computer software programs for the private and public sectors with expertise in designing meteorological applications on Windows and Linux platforms.

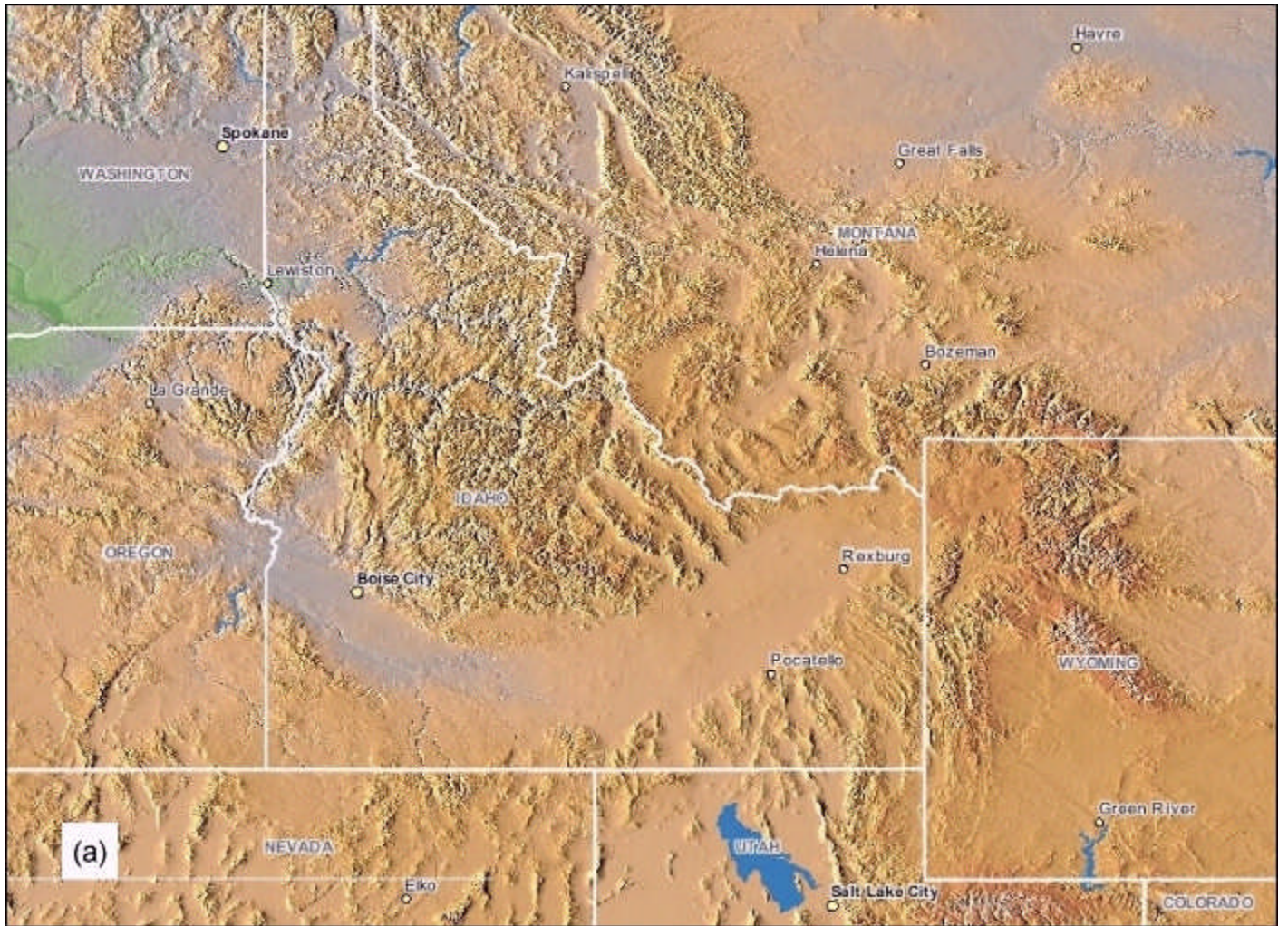


Figure 1a: Regional domain of Northwest United States - state boundaries, names, and major cities

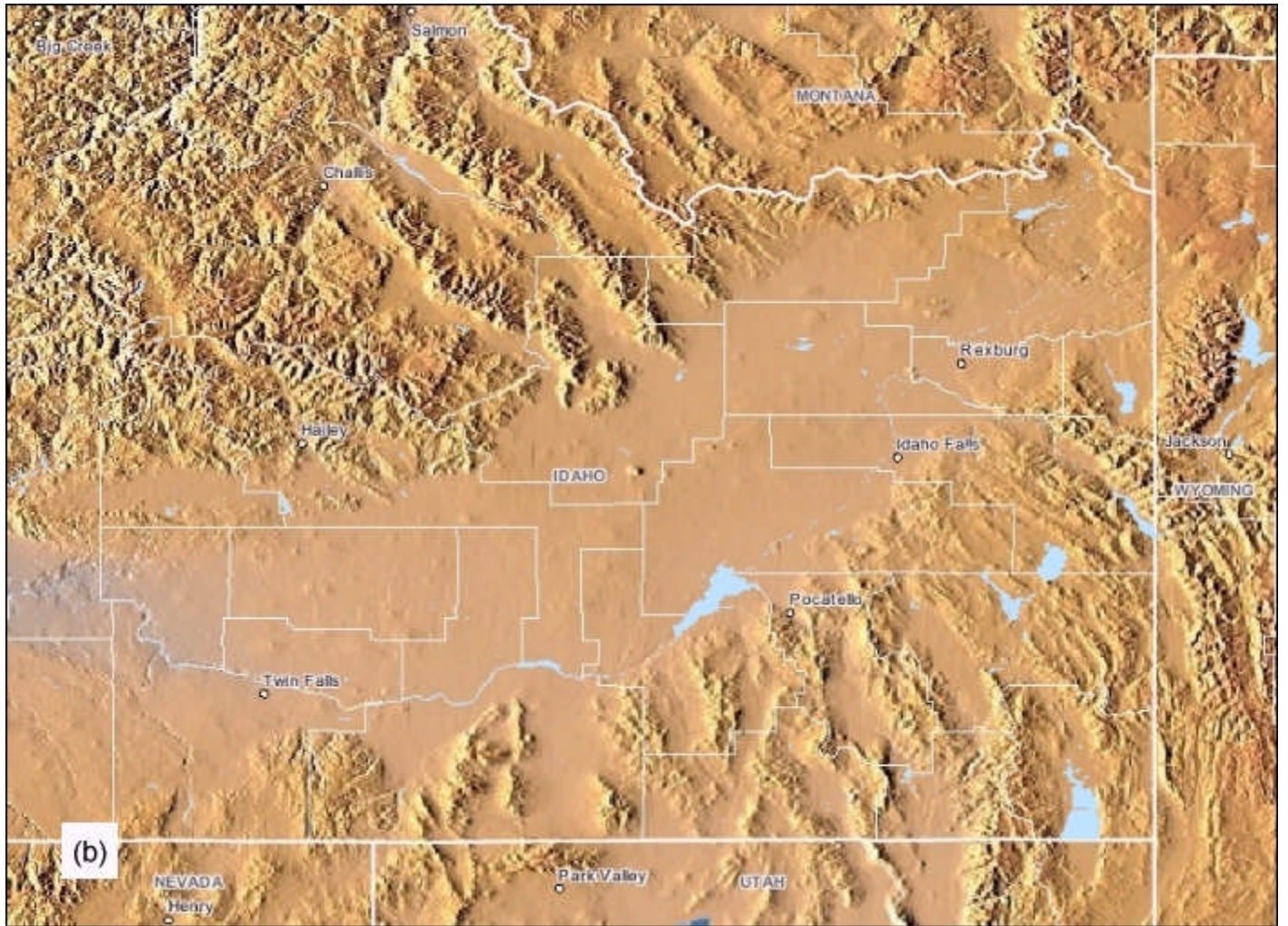


Figure 1b: State domain of Idaho - state boundaries, county outlines, lakes, and major cities in eastern Idaho

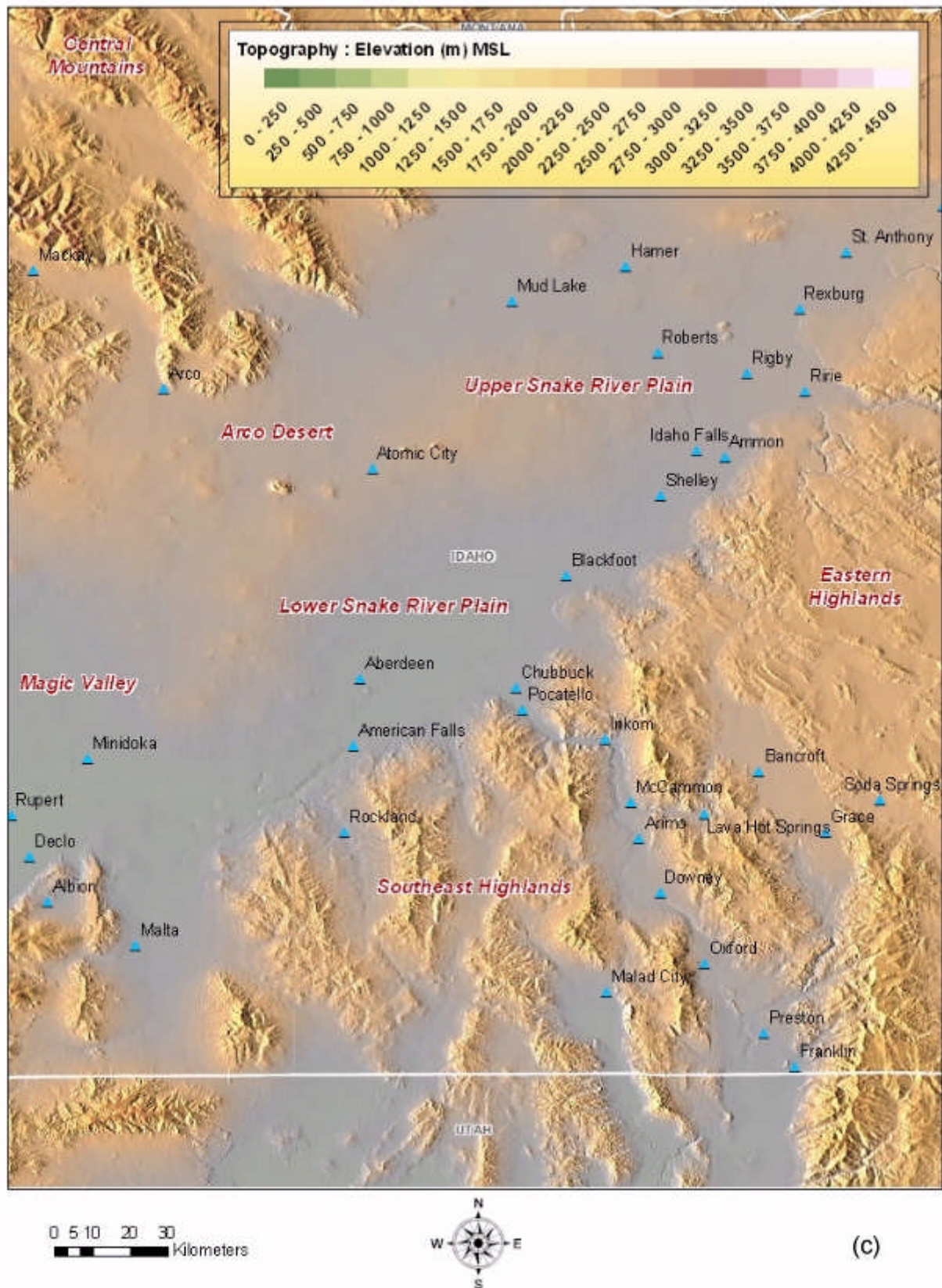


Figure 1c: Local domain of eastern Idaho - state boundaries, state names, geographical regions, and cities

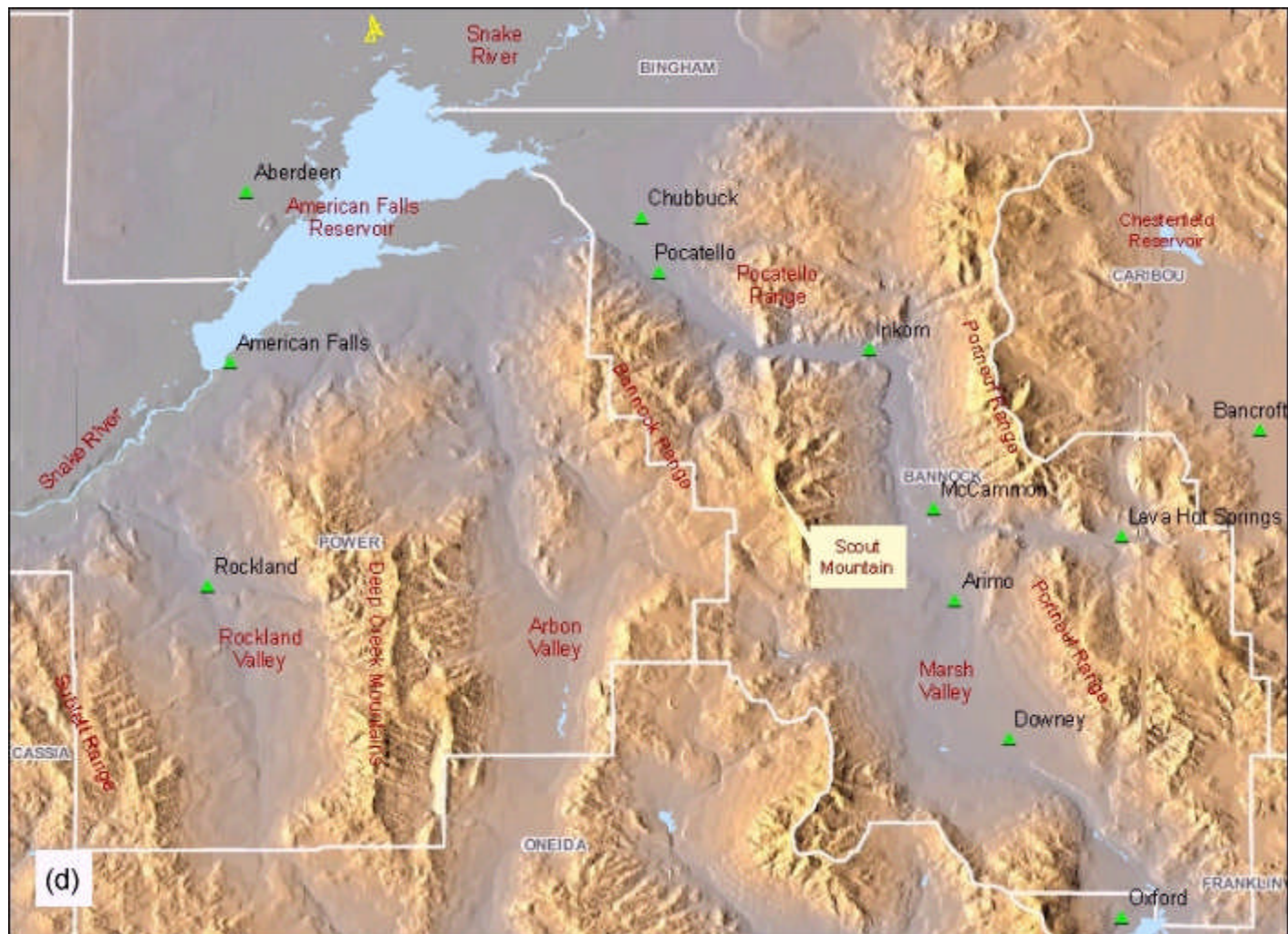


Figure 1d: Local domain of southeast Idaho - county outlines, topographic labels, lakes, WSR-88D tower, and cities

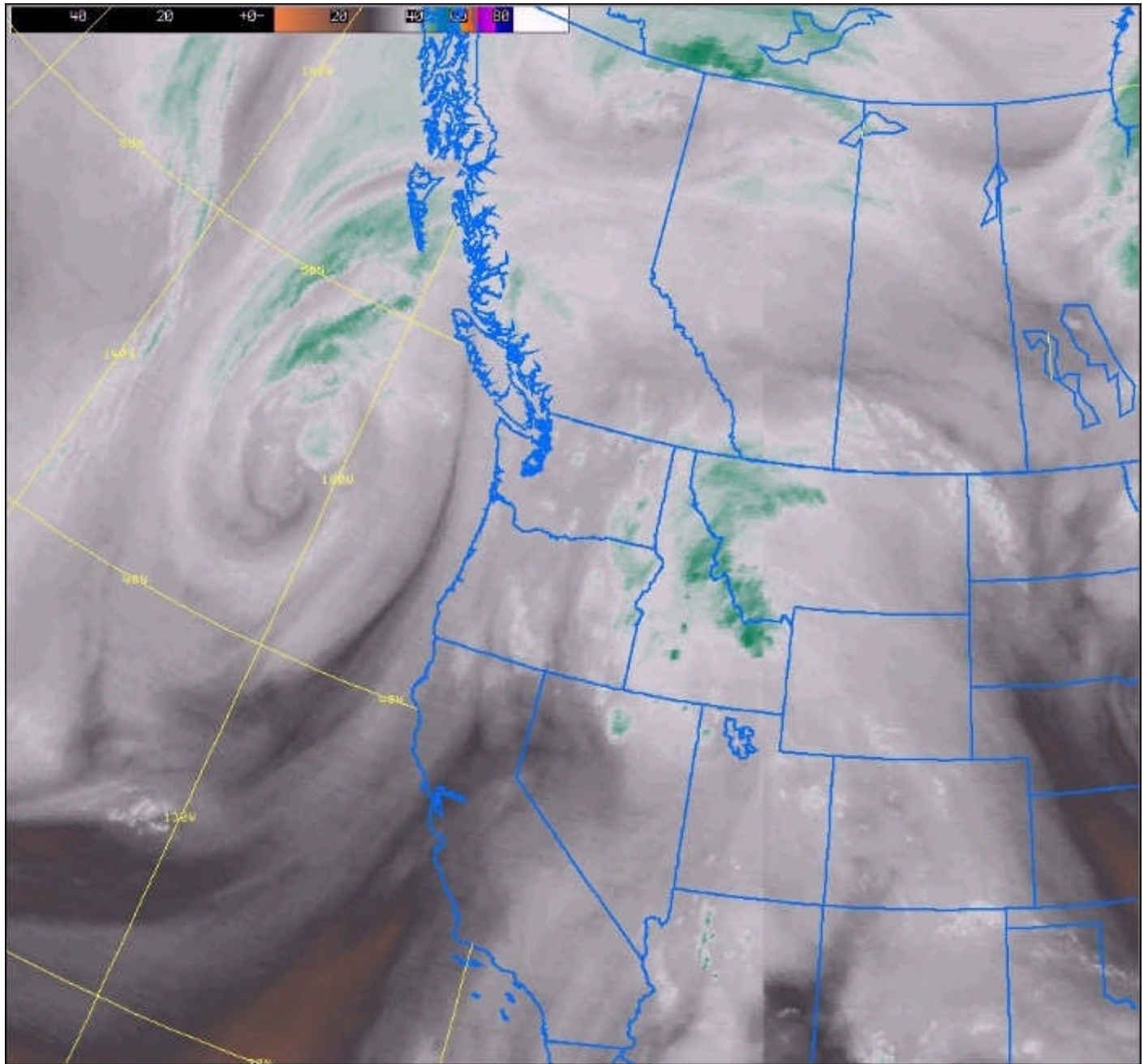


Figure 2: NOAA GOES 4 km Water Vapor Satellite : 1200 UTC 18 July 2004

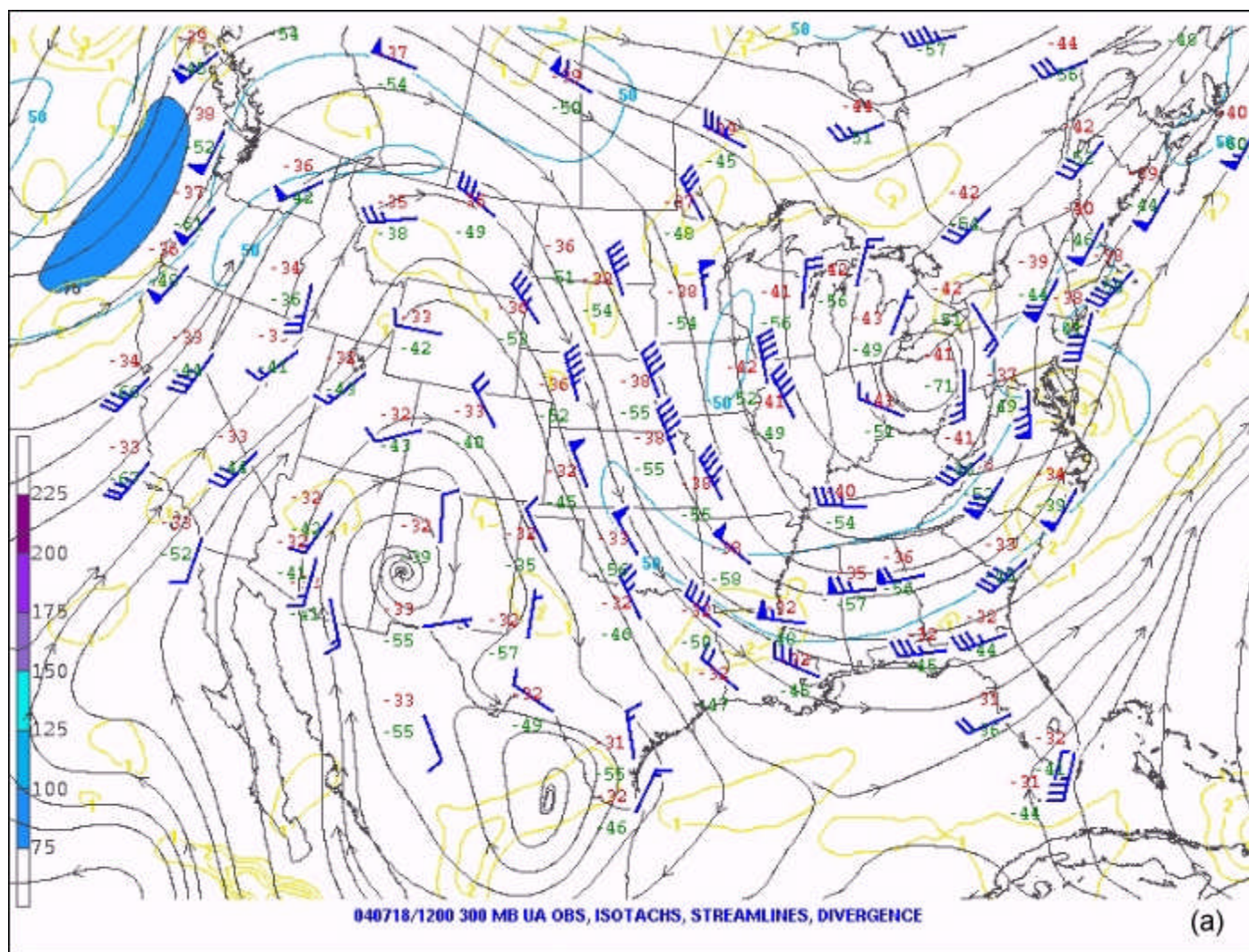


Figure 3a: NOAA SPC 300 mb Objective Analysis : 1200 UTC 18 July 2004

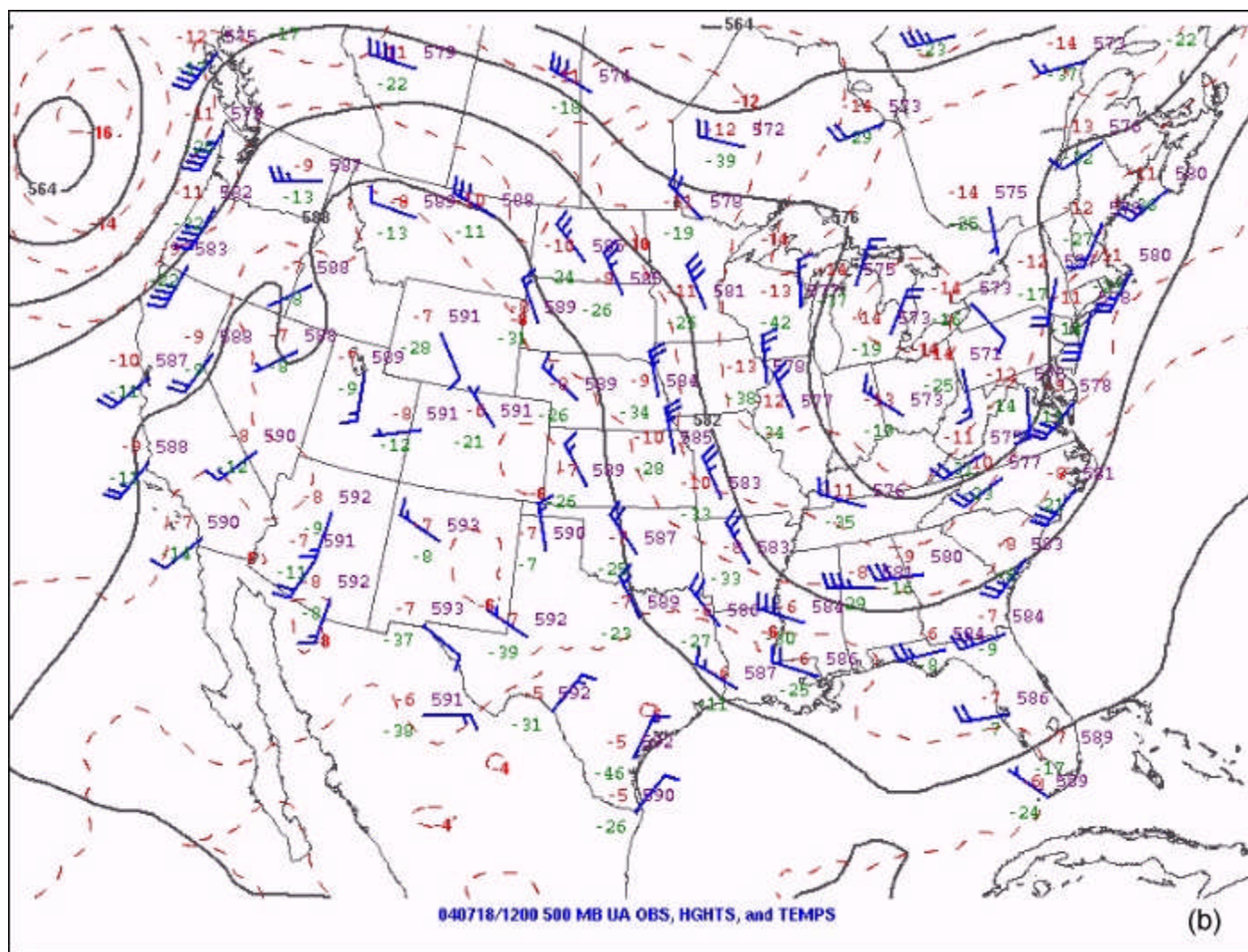


Figure 3b: NOAA SPC 500 mb Objective Analysis : 1200 UTC 18 July 2004

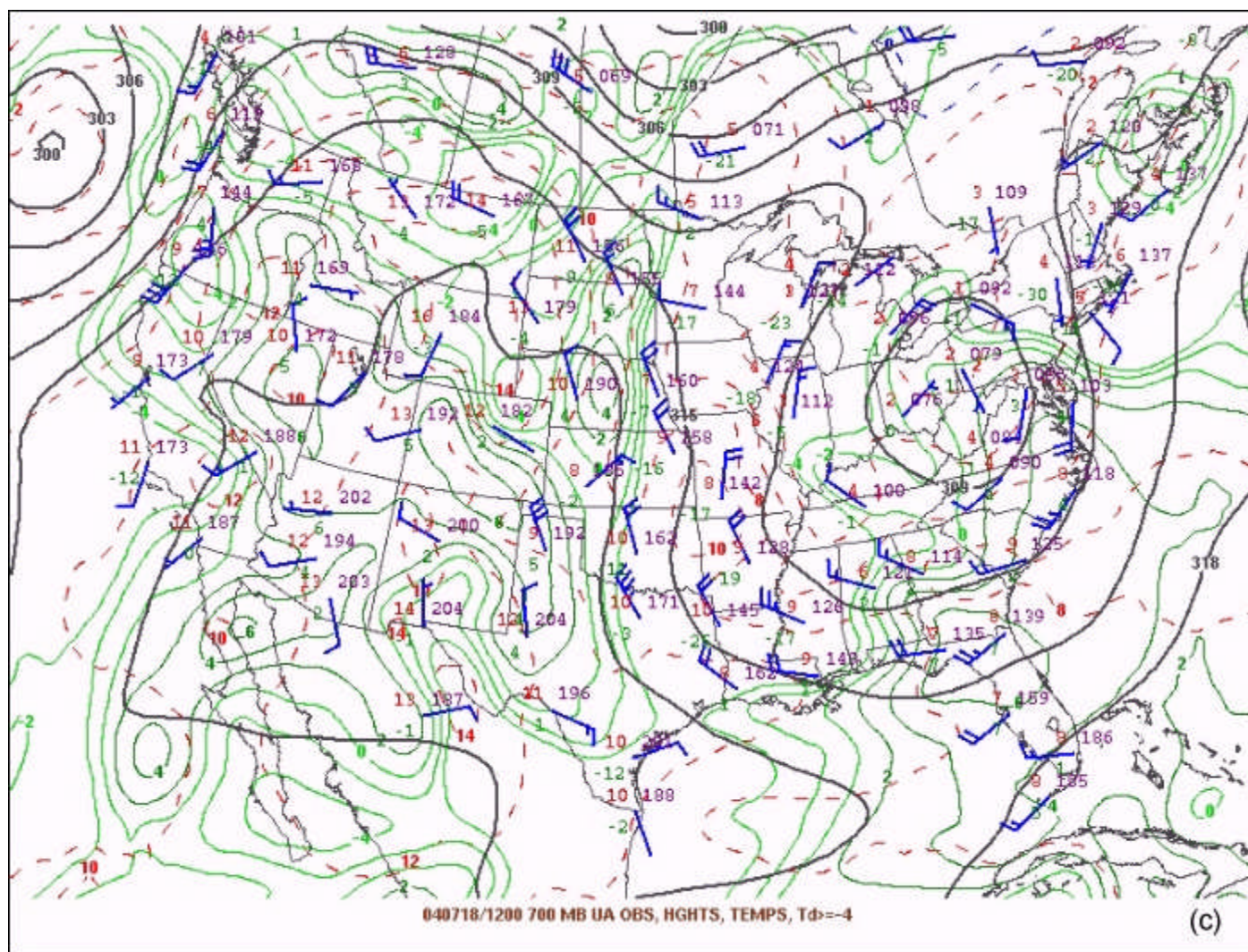


Figure 3c: NOAA SPC 700 mb Objective Analysis : 1200 UTC 18 July 2004

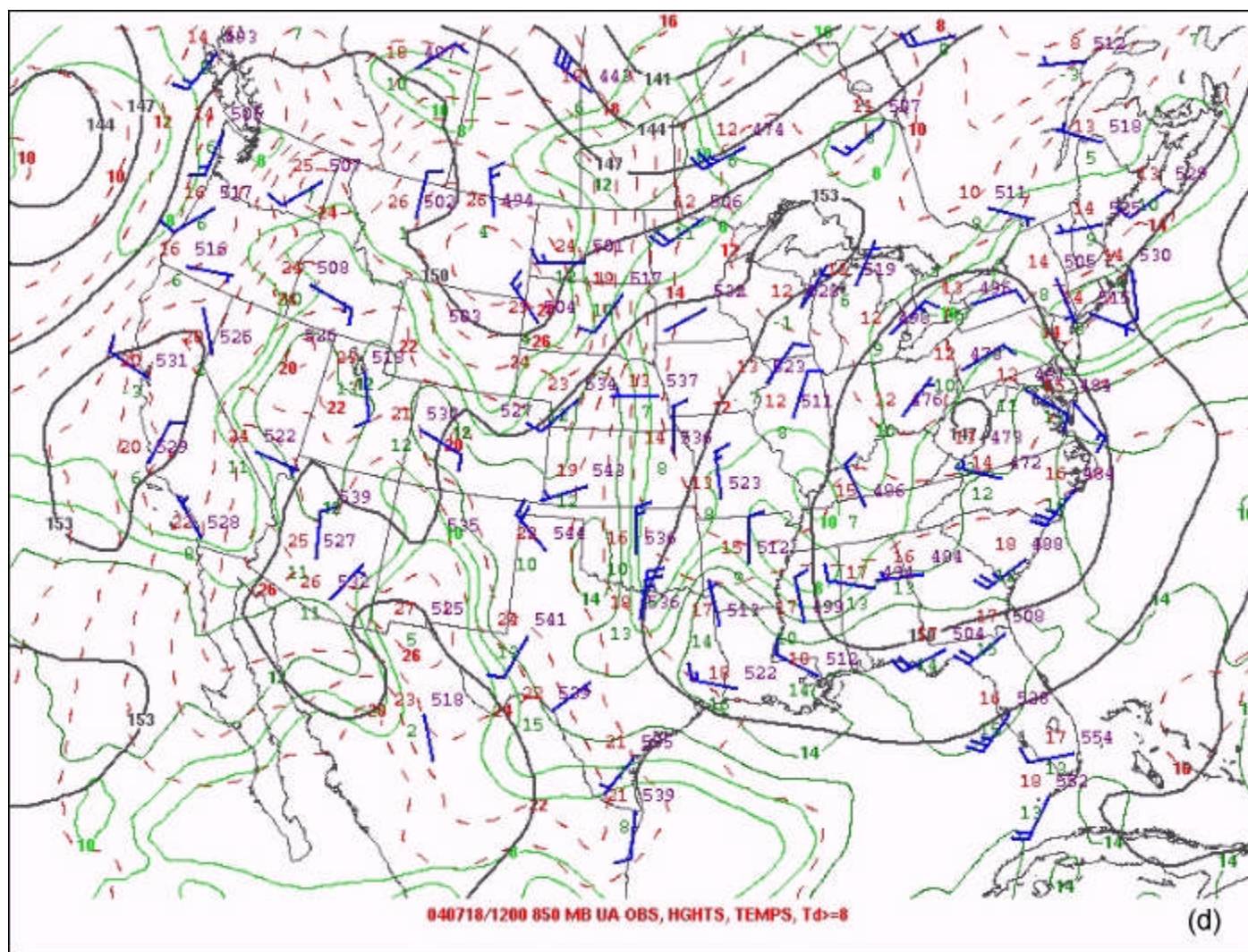


Figure 3d: NOAA SPC 850 mb Objective Analysis : 1200 UTC 18 July 2004

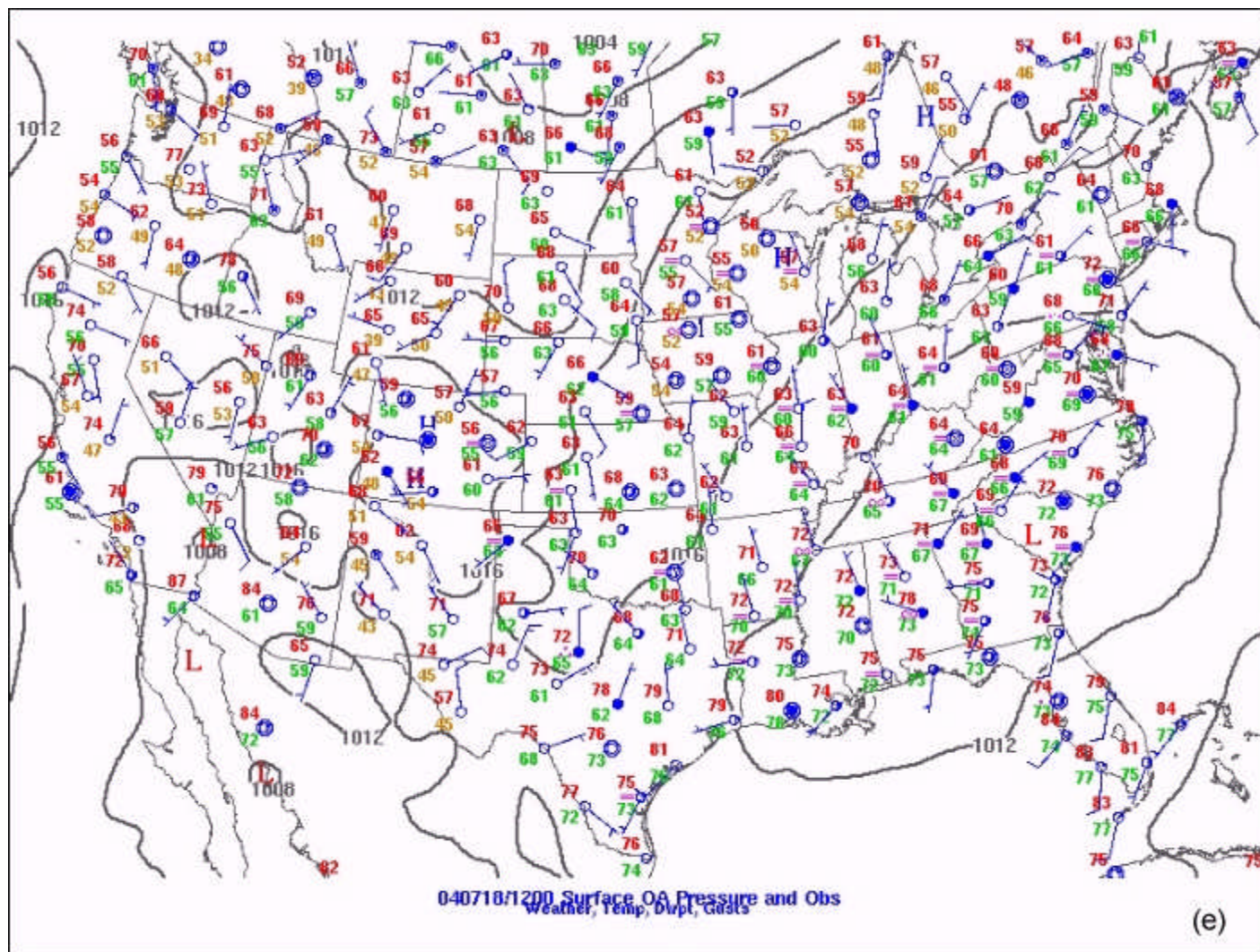


Figure 3e: NOAA SPC Surface Objective Analysis : 1200 UTC 18 July 2004

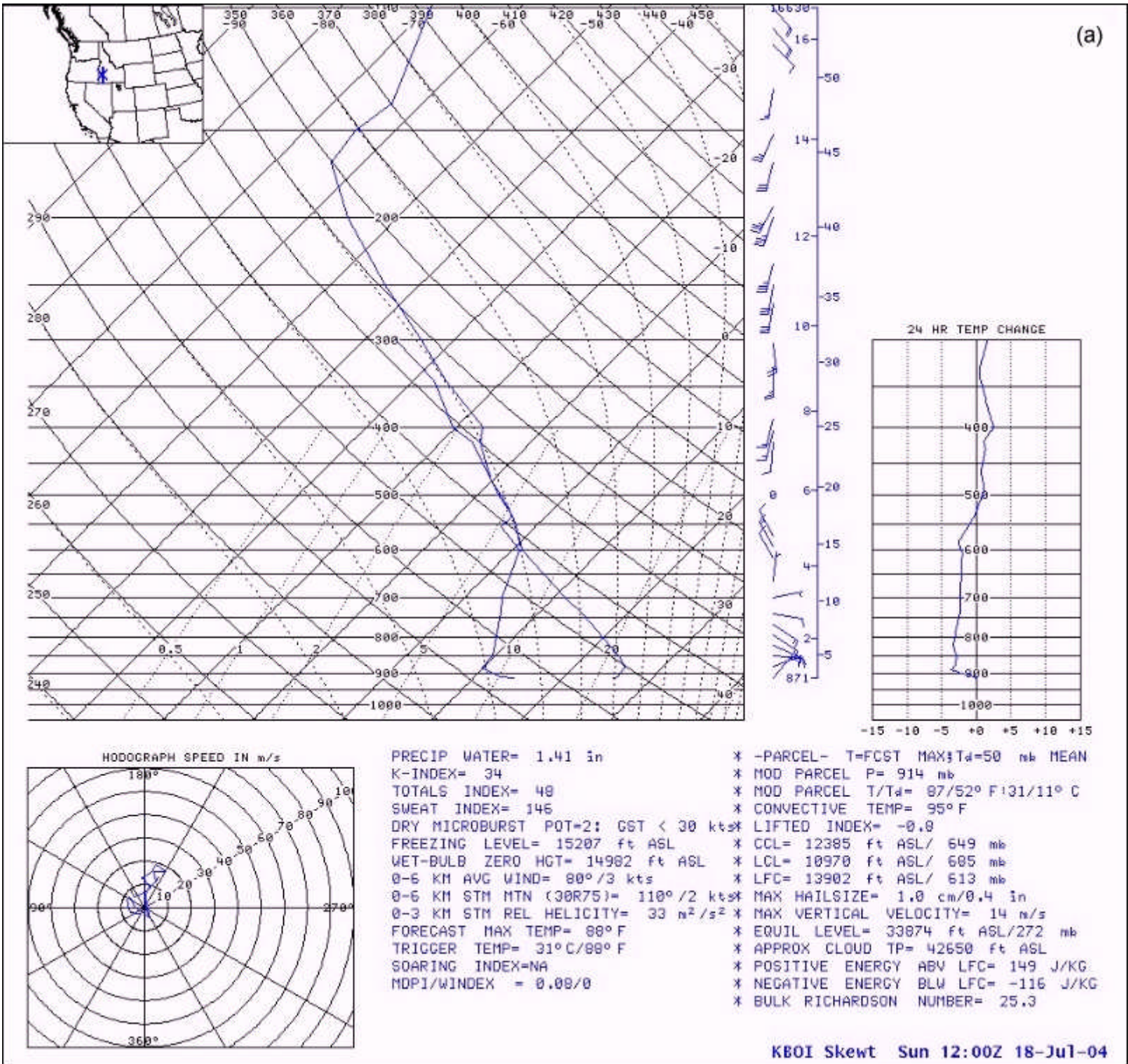


Figure 4a: Observed Sounding for Boise, Idaho (KBOI) : 1200 UTC 18 July 2004

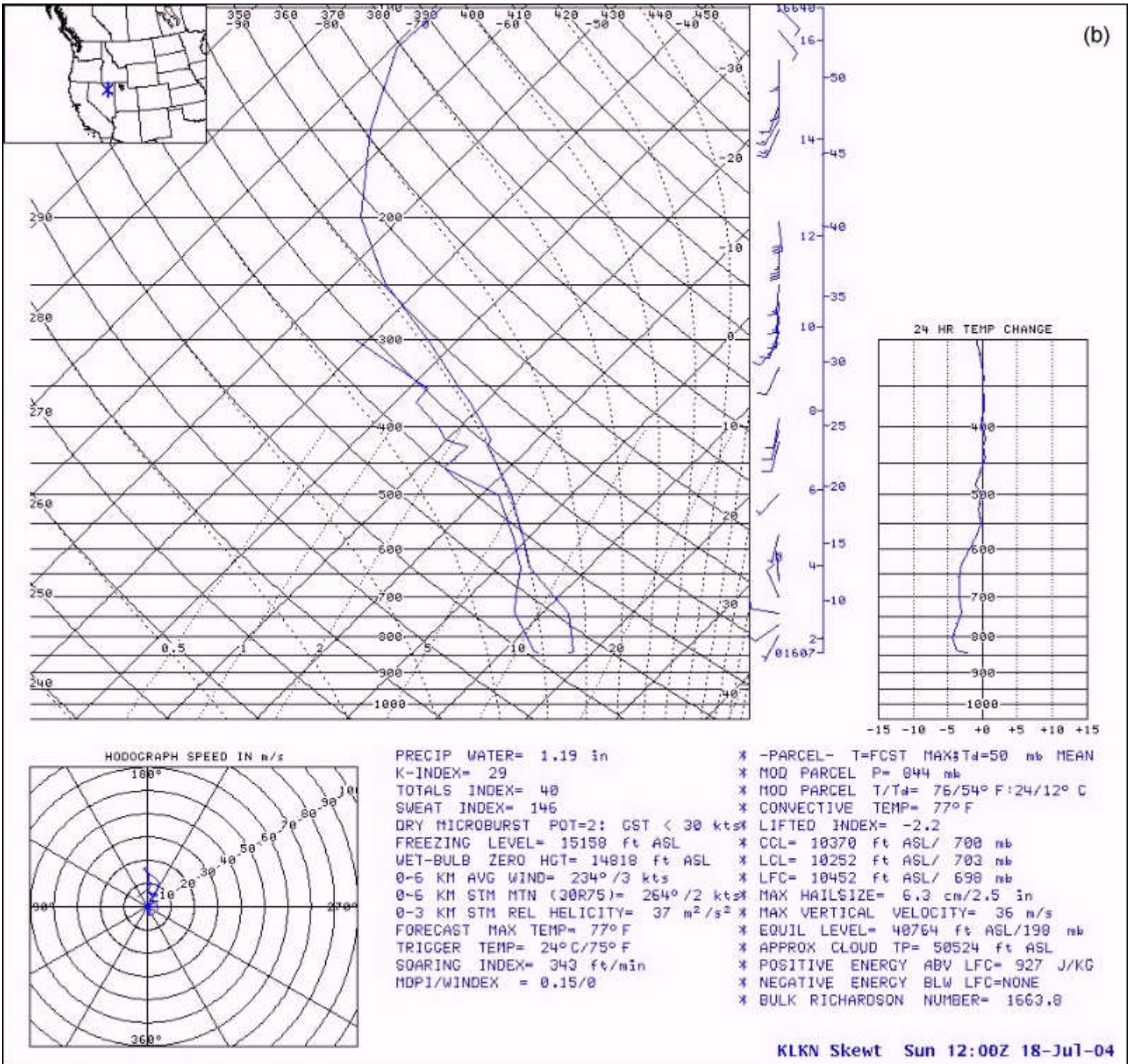


Figure 4b: Observed Sounding for Elko, Nevada (KLKN) : 1200 UTC 18 July 2004

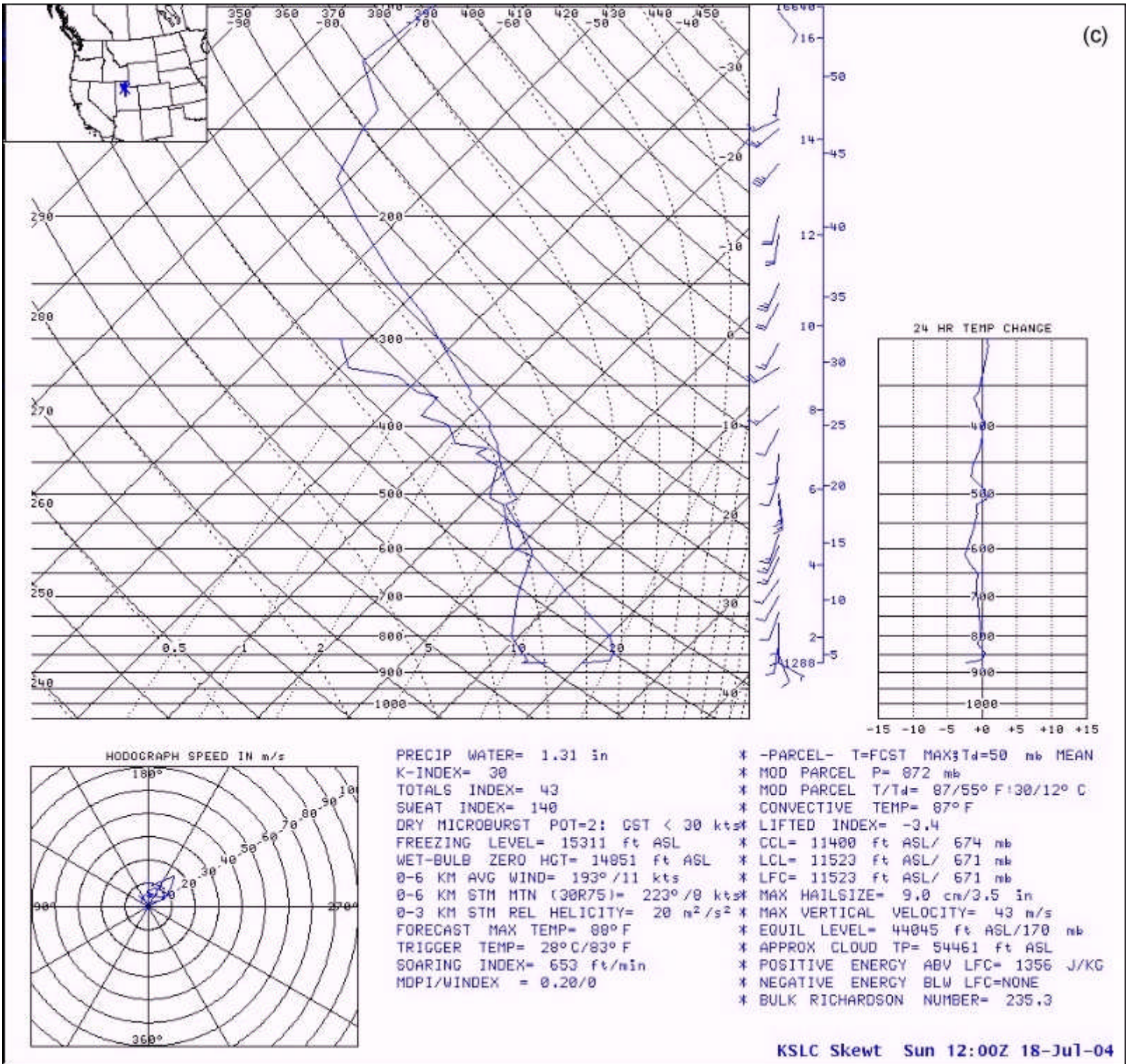


Figure 4c: Observed Sounding for Salt Lake City, Utah (KSLC) : 1200 UTC 18 July 2004

UW MM5-Eta 36km Domain

Init: 12 UTC Sun 18 Jul 04

Fest: 0 h

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

Temperature at 300mb (°C)

Geopotential Height at 300mb (m)

Wind at 300mb (full barb = 10kts)

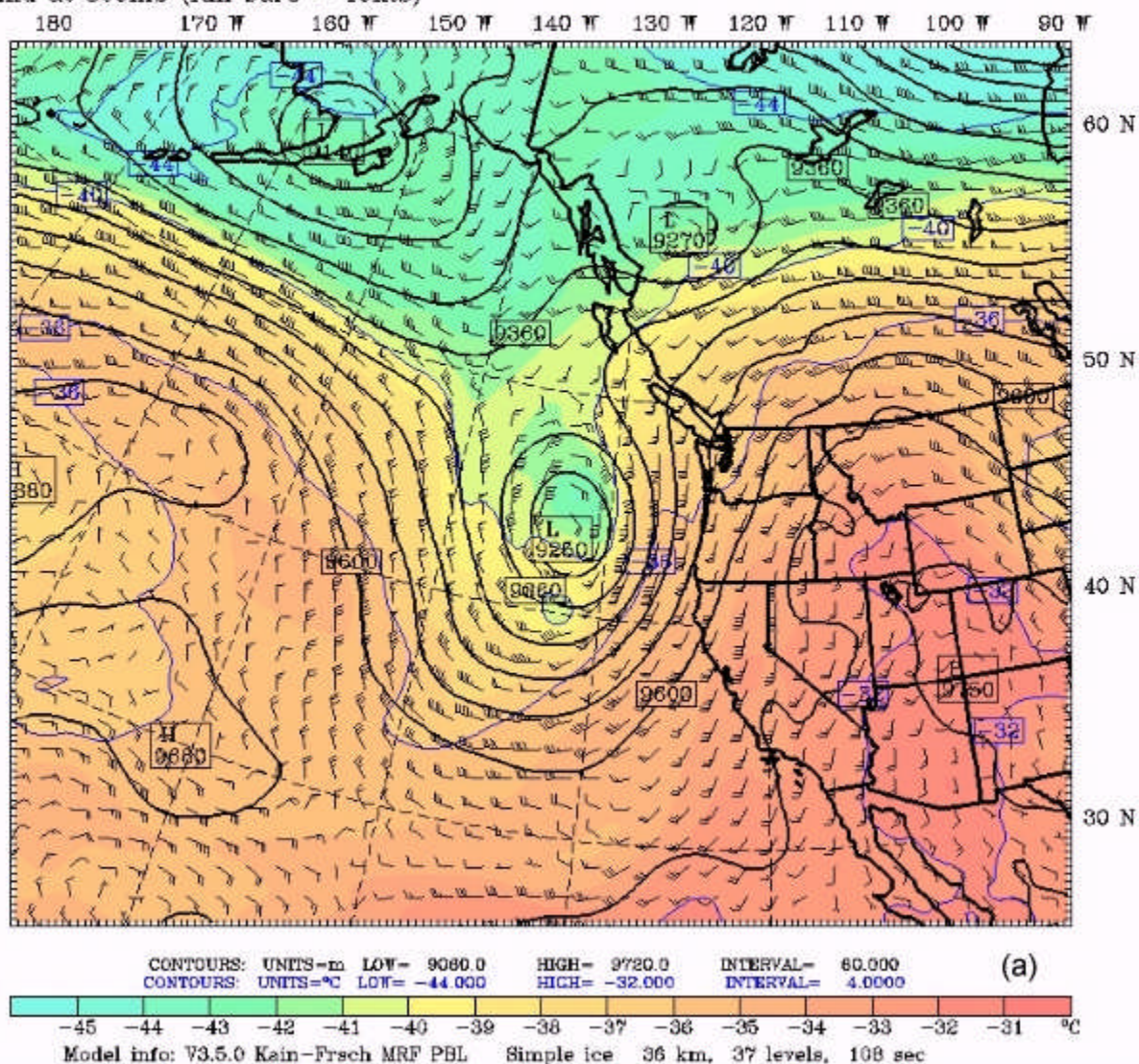


Figure 5a: MM5-ETA 300 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 36km Domain

Init: 12 UTC Sun 18 Jul 04

Fest: 0 h

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

Temperature at 500mb (°C)

Geopotential Height at 500mb (m)

Wind at 500mb (full barb = 10kts)

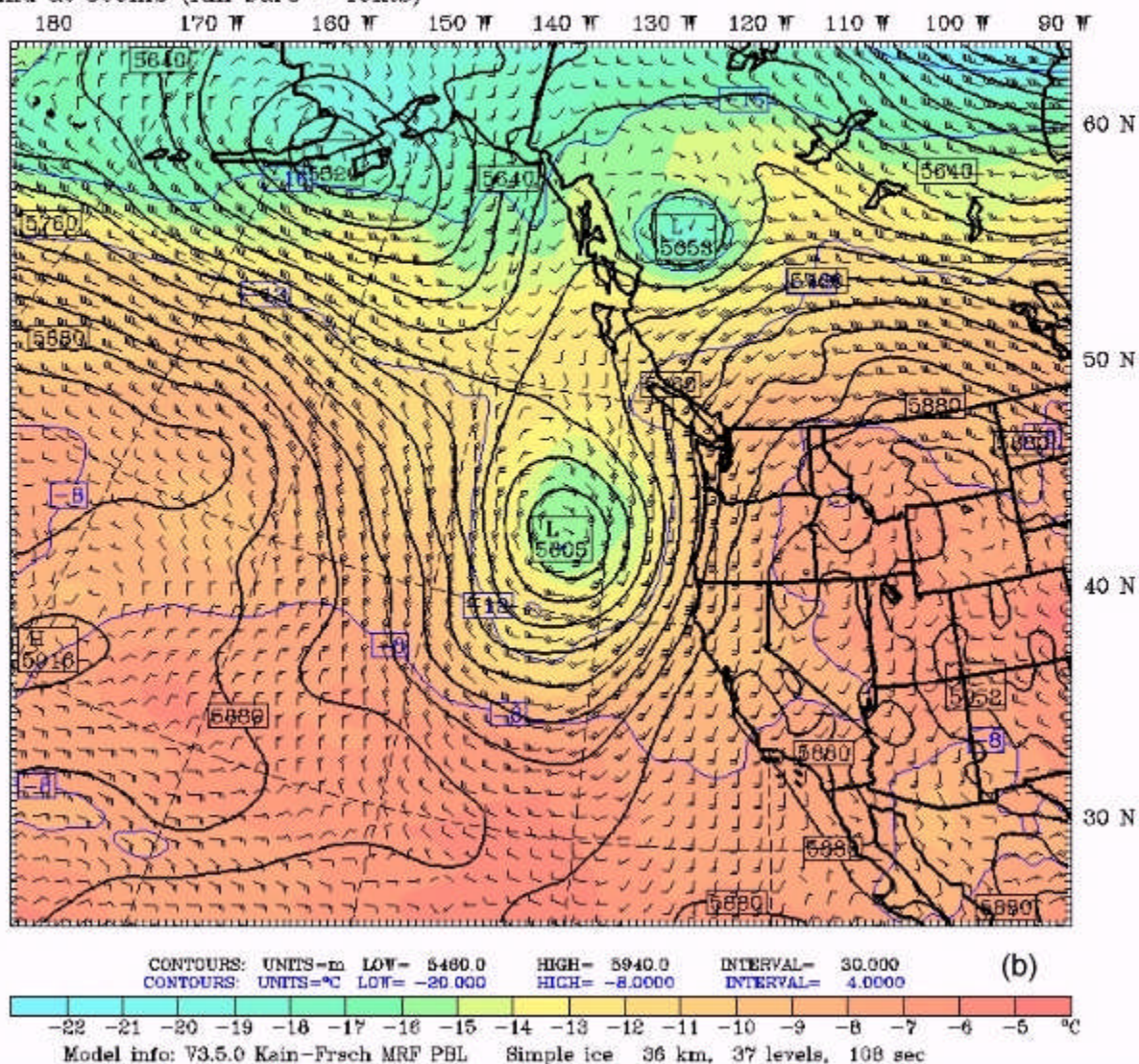


Figure 5b: MM5-ETA 500 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 0 h

300 mb wind speed (m/s)

Temperature at 300mb (°C)

Geopotential Height at 300mb (m)

Wind at 300mb (full barb = 10kts)

Init: 12 UTC Sun 18 Jul 04

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

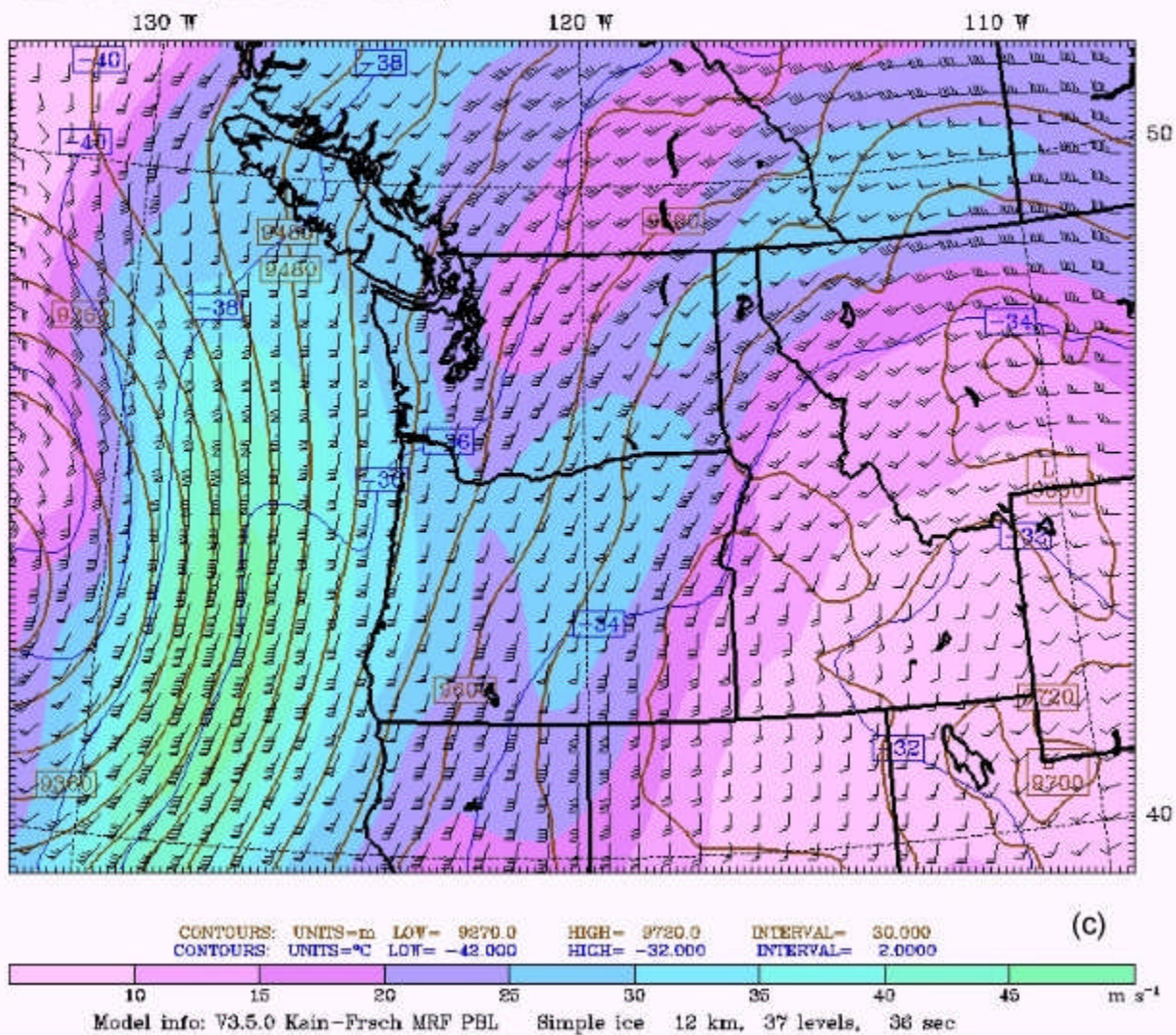


Figure 5c: MM5-ETA 300 mb wind speed (m s^{-1}), temperature ($^{\circ}\text{C}$), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 0 h

Absolute vorticity

Geopotential Height at 500mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

at pressure - 500 hPa

sm- 2

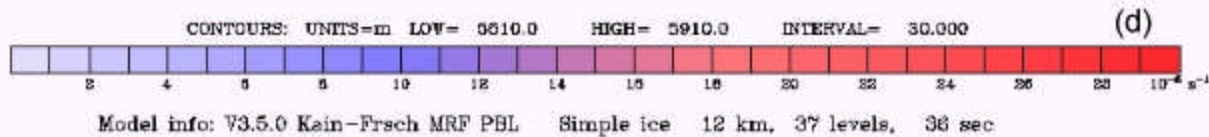
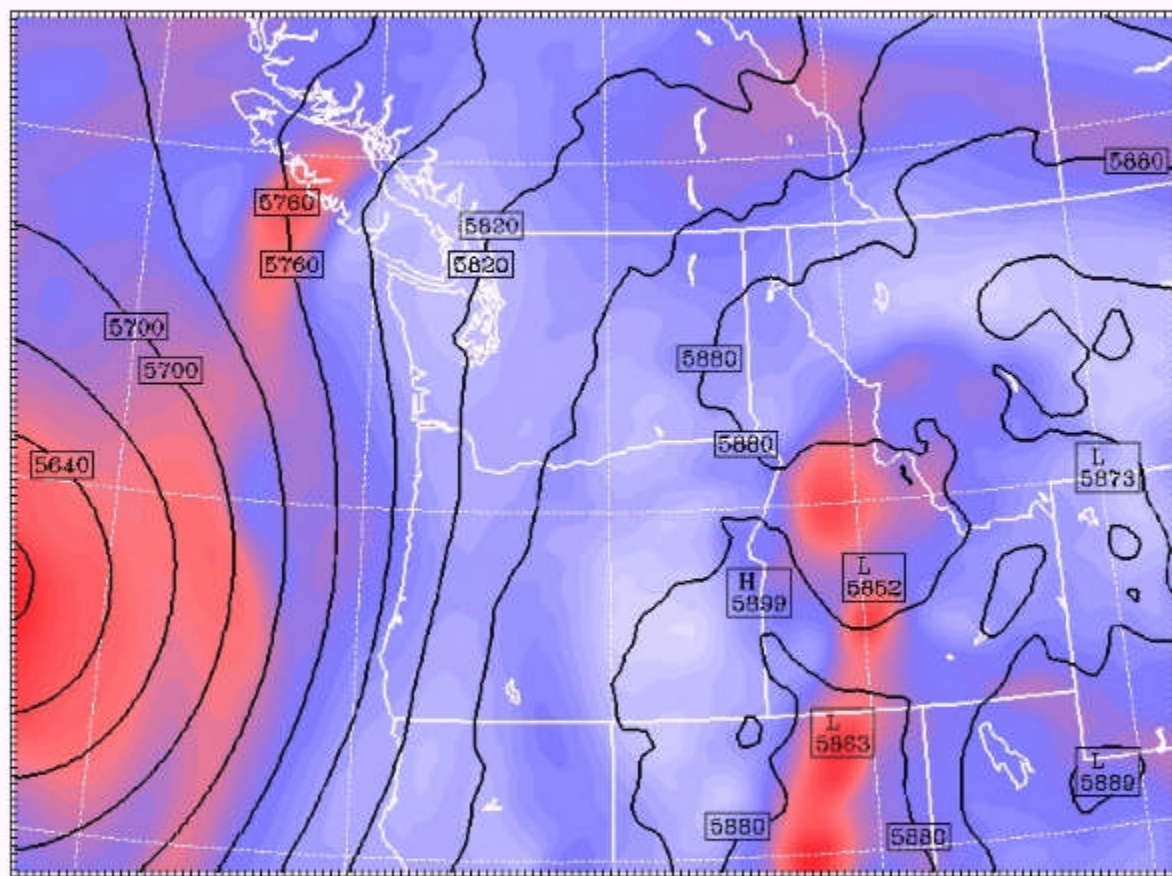


Figure 5d: MM5-ETA 500 mb absolute vorticity (s^{-1}) and geopotential height (m)

UW MM5-Eta 12km Domain

Init: 12 UTC Sun 18 Jul 04

Fest: 0 h

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

Temperature at 700mb (°C)

Geopotential Height at 700mb (m)

Wind at 700mb (full barb = 10kts)

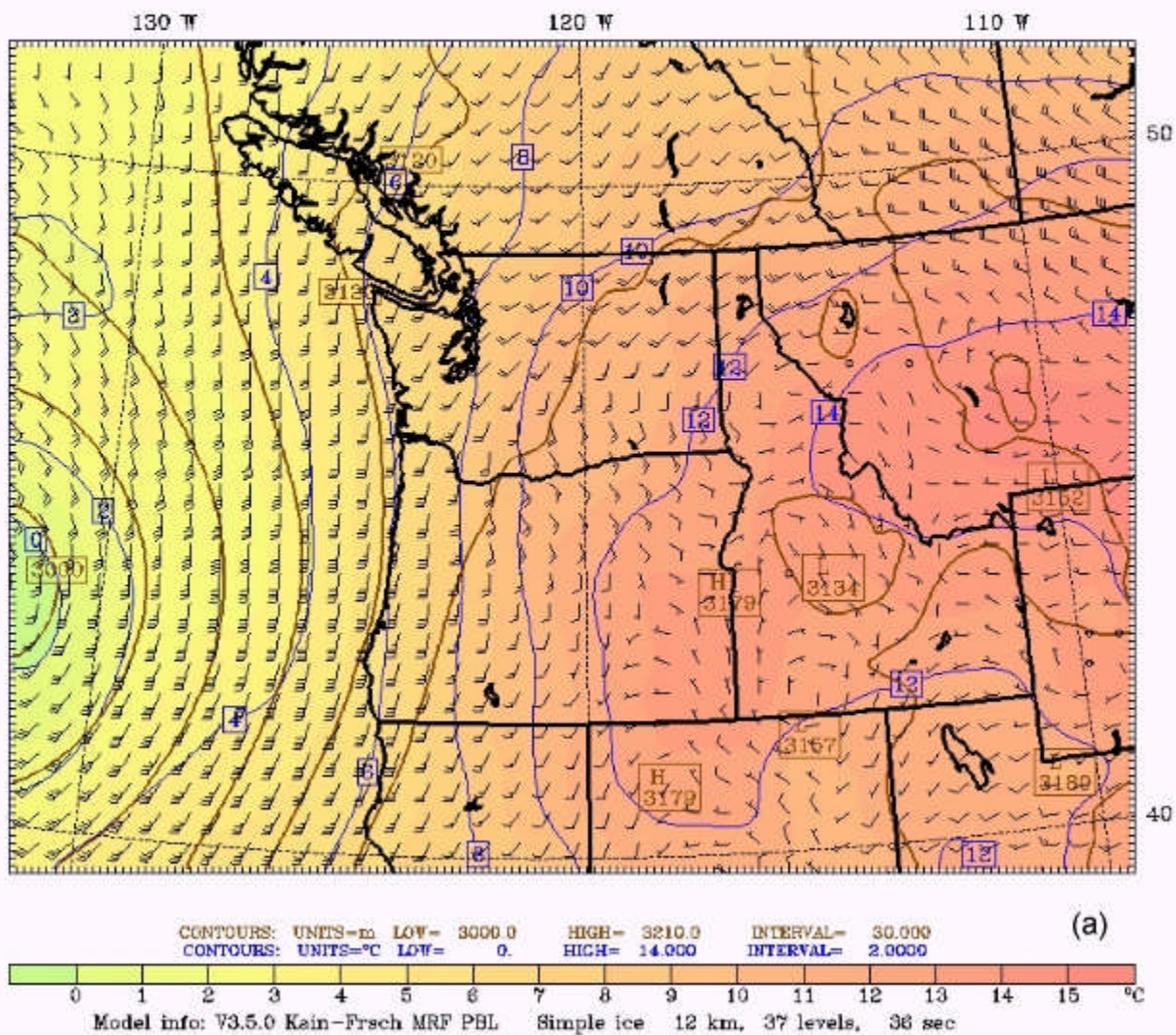


Figure 6a: MM5-ETA 700 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 0 h

Init: 12 UTC Sun 18 Jul 04

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

Temperature at 850mb (°C)

Geopotential Height at 850mb (m)

Wind at 850mb (full barb = 10kts)

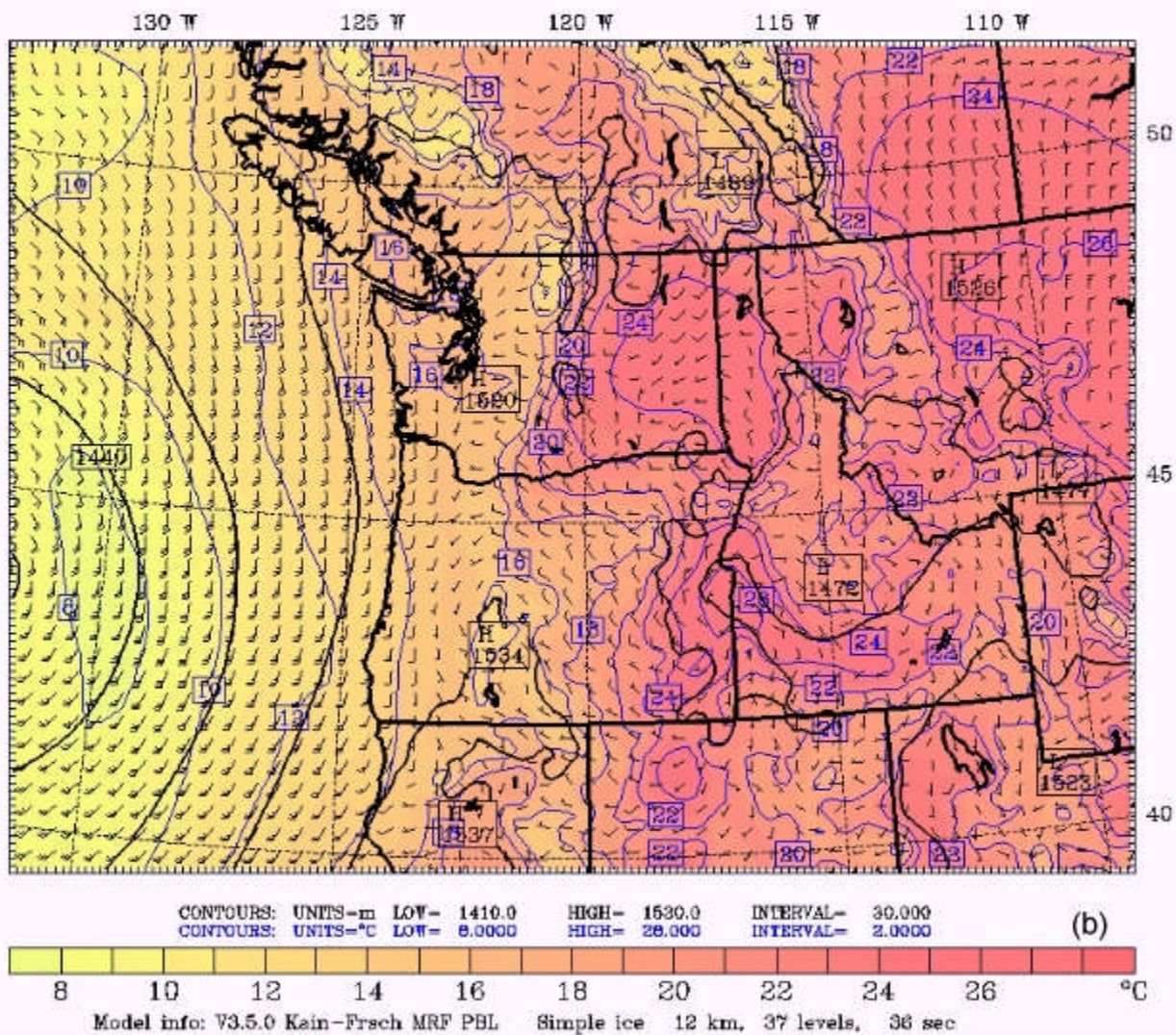


Figure 6b: MM5-ETA 850 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 0 h

Temperature at 925 mb (°C)

Sea Level Pressure (hPa)

Wind at 10m (full barb = 10kts)

Init: 12 UTC Sun 18 Jul 04

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

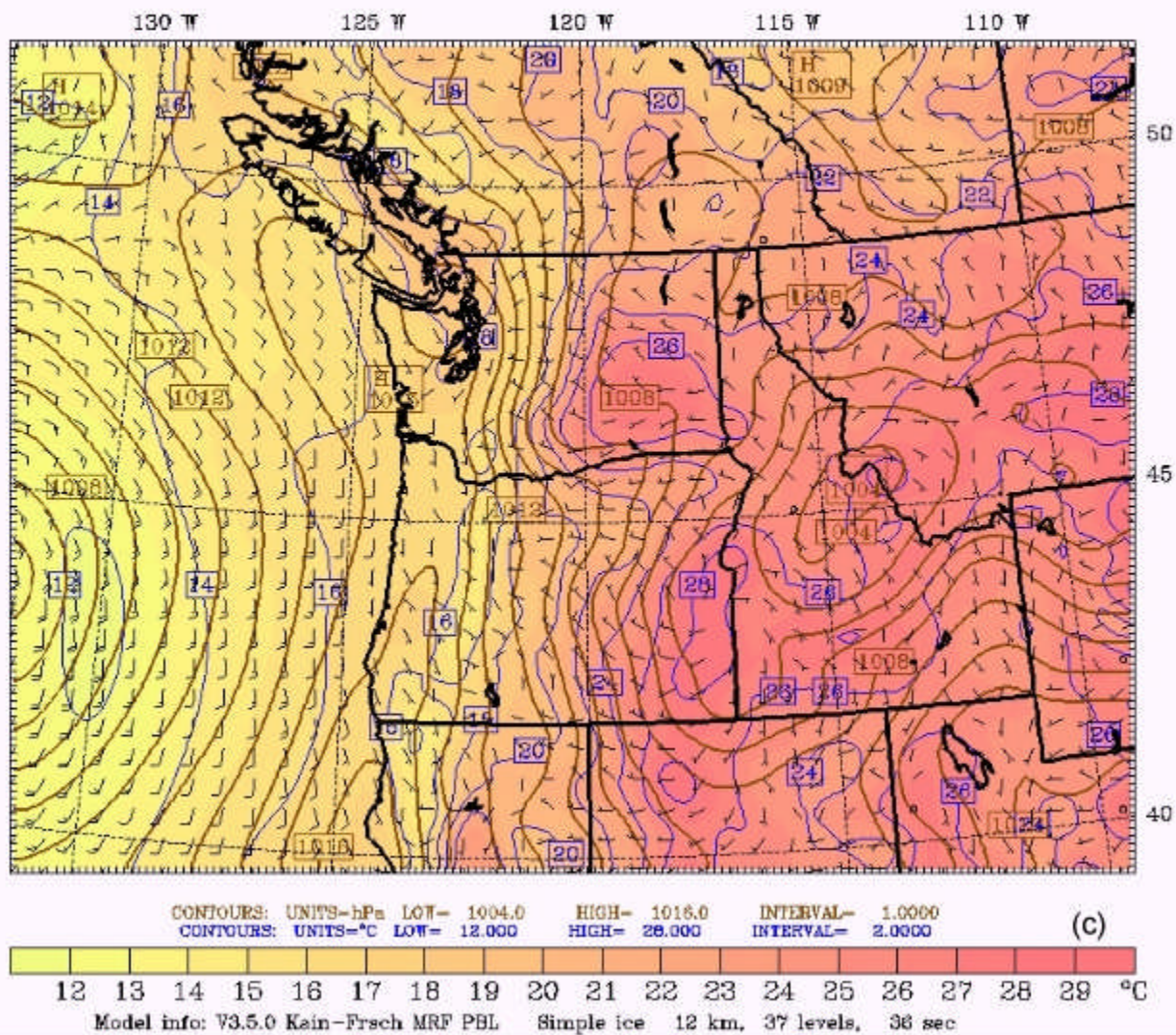


Figure 6c: MM5-ETA 925 mb temperature (°C), mean sea-level pressure (hPa), and 10 m wind (knots)

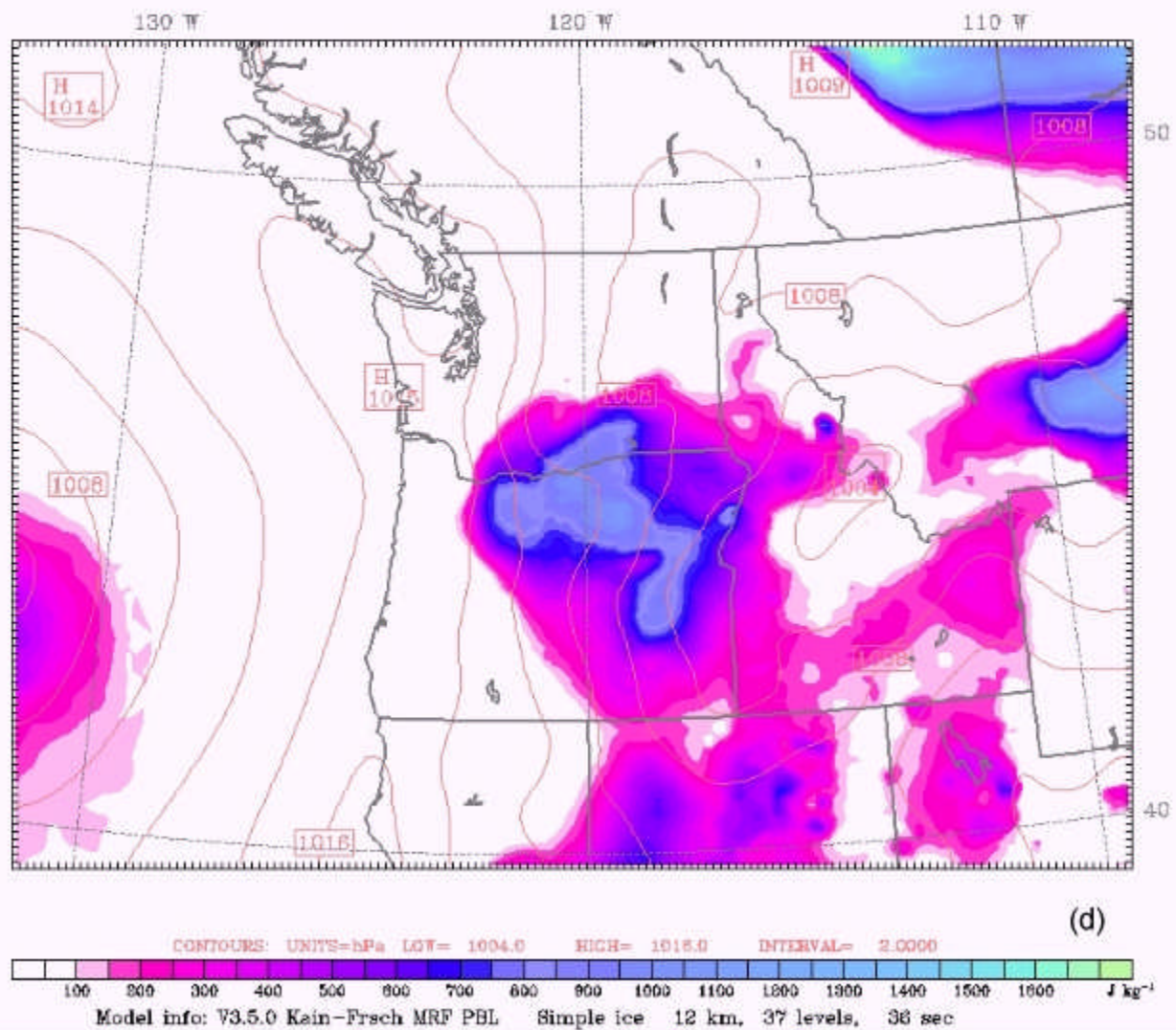
Init: 12 UTC Sun 18 Jul 04

Fest: 0 h

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

Maximum CAPE (J/kg)

Sea Level Pressure (hPa)



UW MM5-Eta 12km Domain

Fest: 0 h

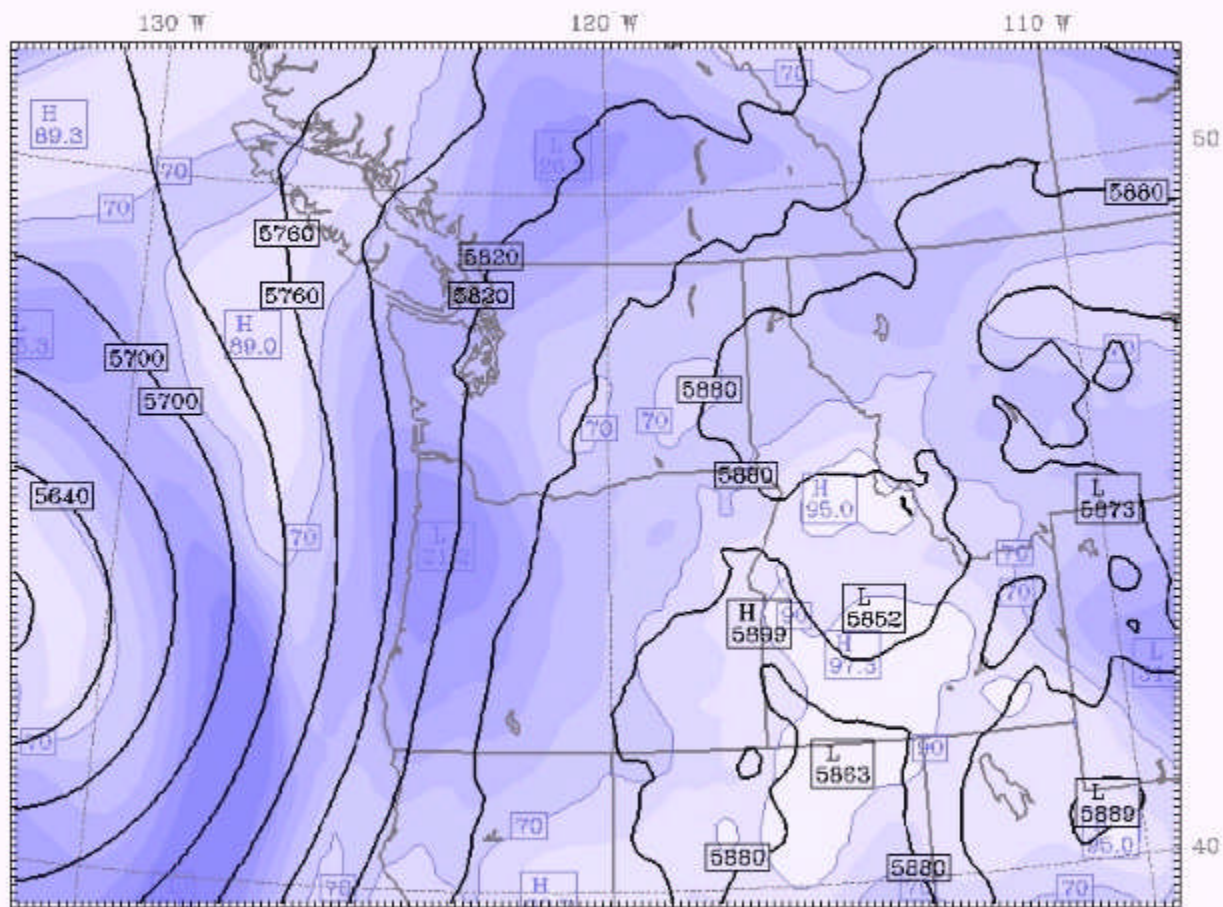
Relative humidity (w.r.t. water)

Geopotential Height at 500mb (m)

Init: 12 UTC Sun 18 Jul 04

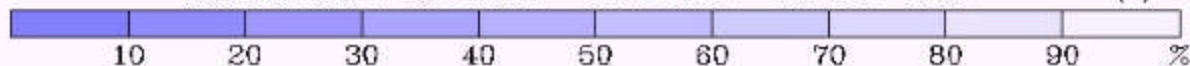
Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

at pressure - 500 hPa



CONTOURS: UNITS=m LOW= 5610.0 HIGH= 5910.0 INTERVAL= 30.000

(a)



Model info: V3.5.0 Kain-Franch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 7a: MM5-ETA 500 mb relative humidity (%) and geopotential height (m)

Init: 12 UTC Sun 18 Jul 04

Fest: 0 h

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

Relative humidity (w.r.t. water)

at pressure = 700 hPa

Geopotential Height at 700mb (m)

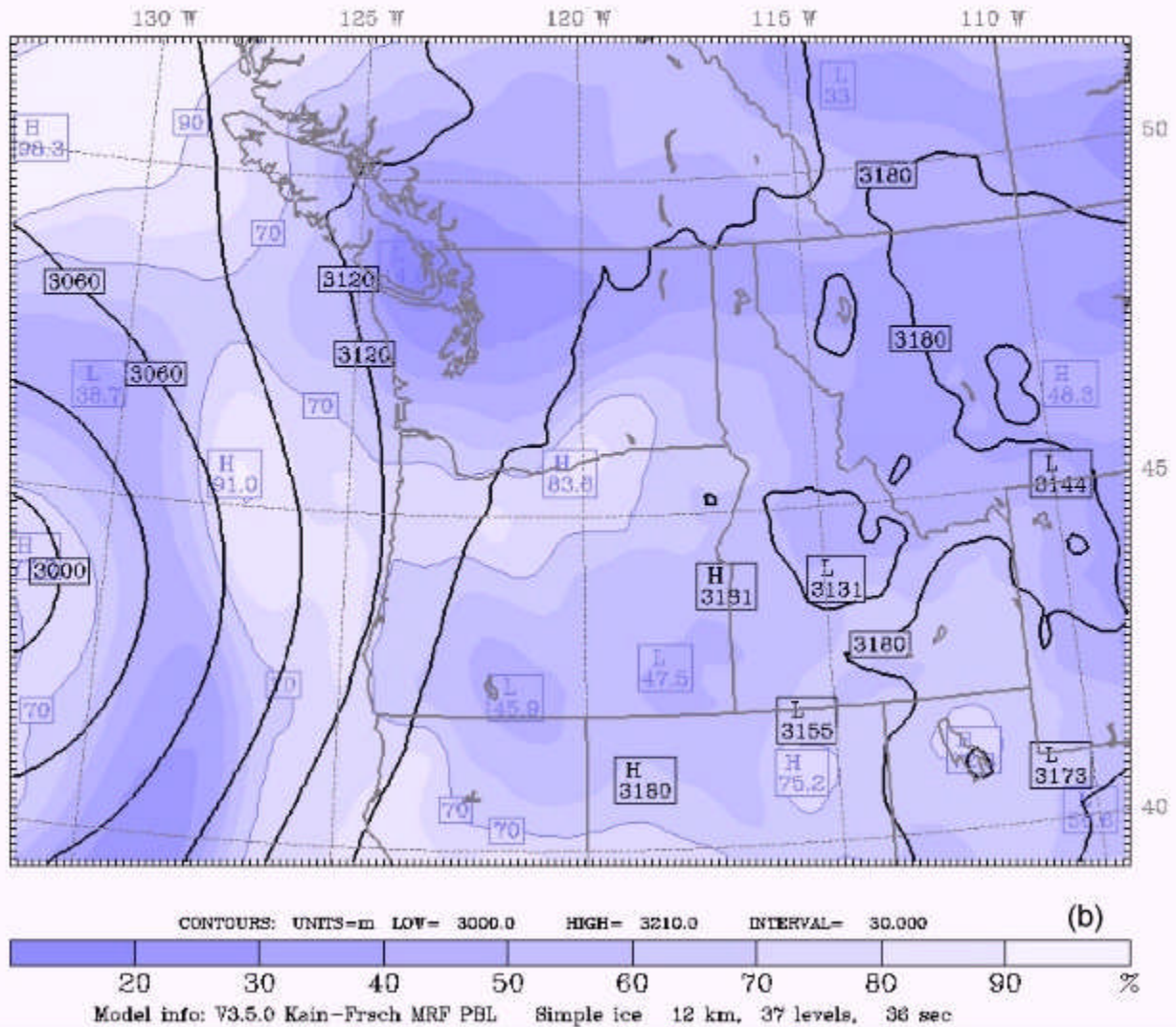


Figure 7b: MM5-ETA 700 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

Fest: 0 h

Relative humidity (w.r.t. water)

Geopotential Height at 850mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 12 UTC Sun 18 Jul 04 (05 PDT Sun 18 Jul 04)

at pressure - 850 hPa

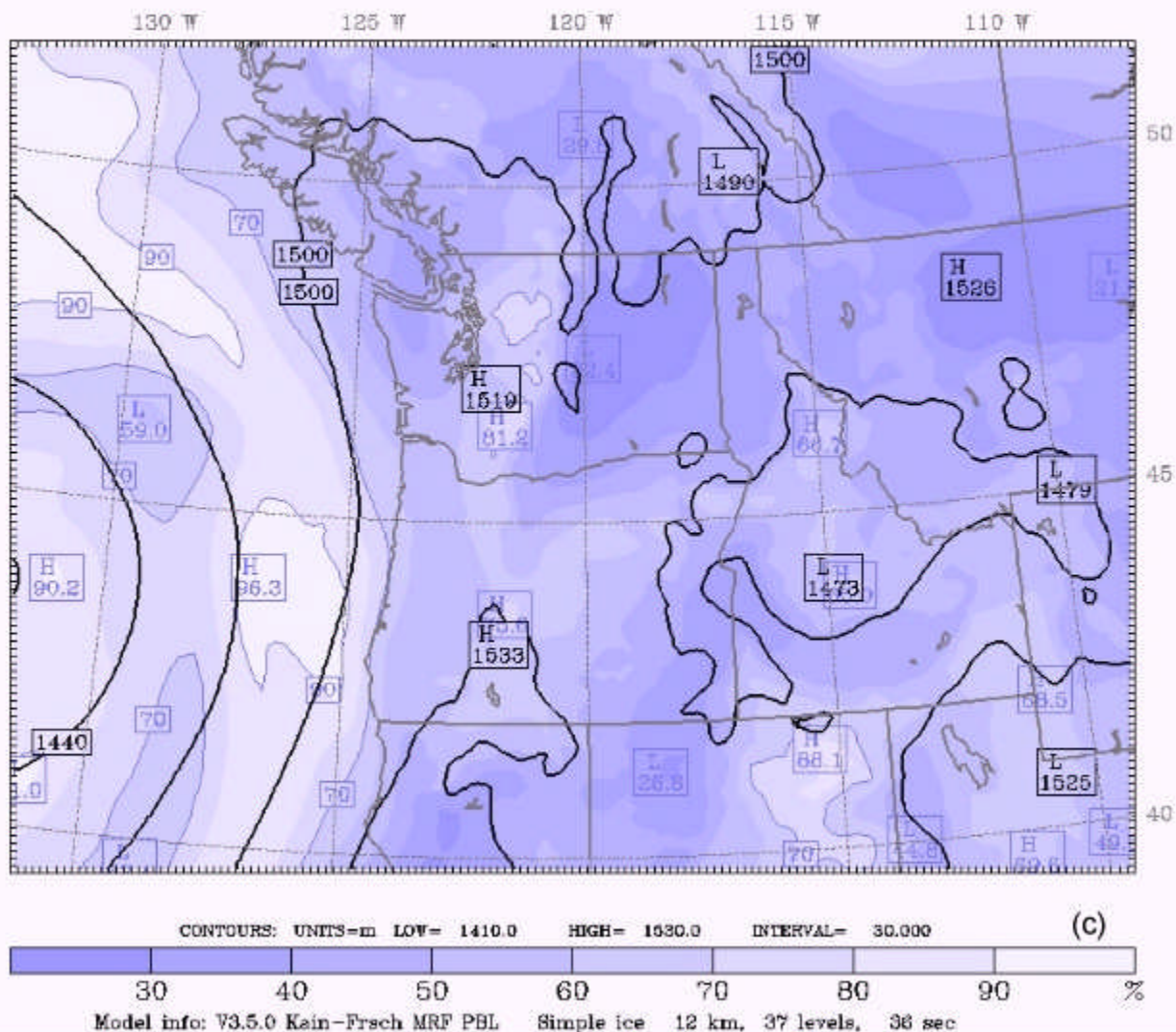


Figure 7c: MM5-ETA 850 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

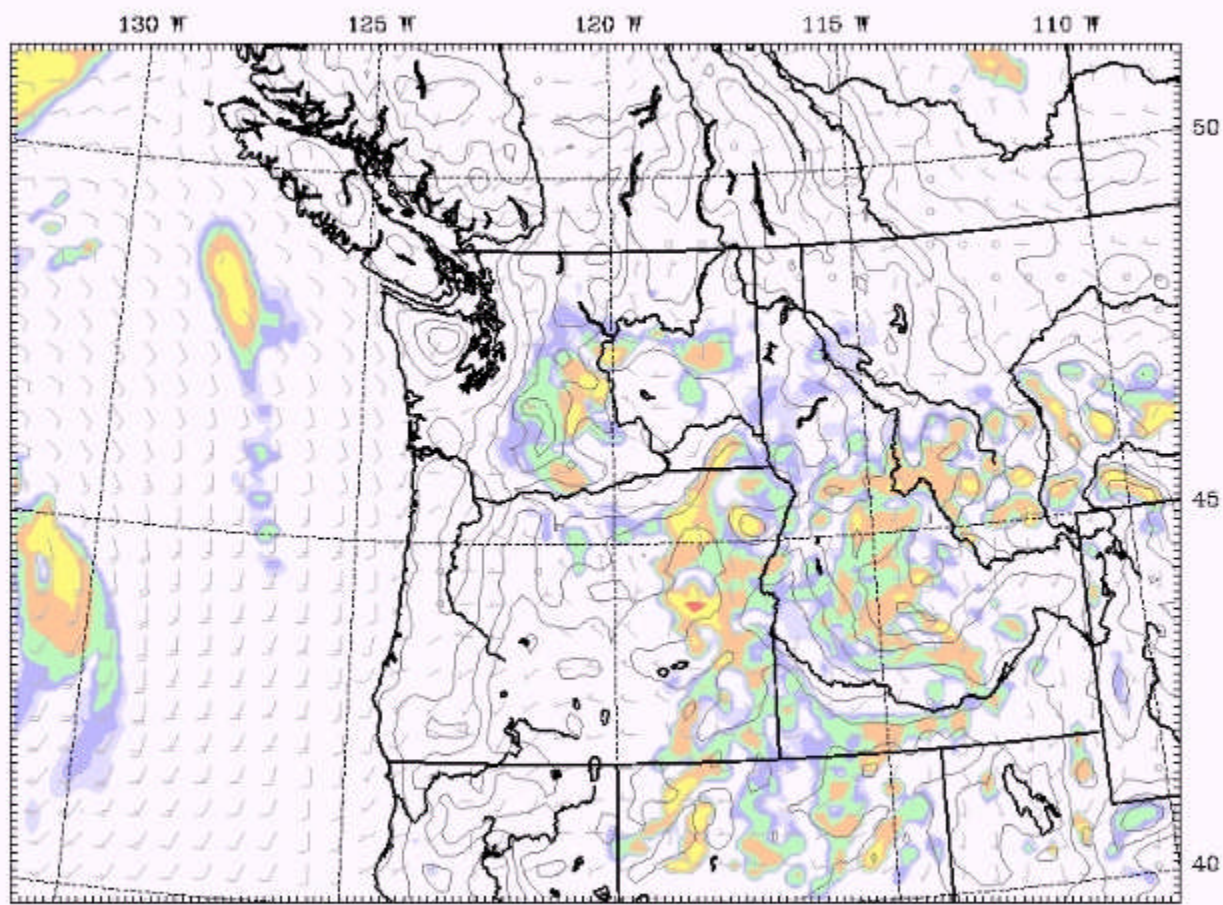
Init: 12 UTC Sun 18 Jul 04

Fest: 6 h

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

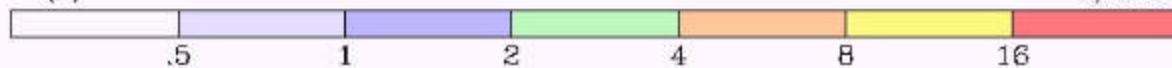
Total Precip in past 3 hrs (.01in)

Wind at 10m (full barb = 10kts)



(d)

1/100 inch



Model info: V3.5.0 Kain-Frsc MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 7d: MM5-ETA total precipitation in past 3 hours (inches) and 10 m wind speed (knots)

UW MM5-Eta 36km Domain

Init: 12 UTC Sun 18 Jul 04

Fest: 6 h

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

Temperature at 300mb (°C)

Geopotential Height at 300mb (m)

Wind at 300mb (full barb = 10kts)

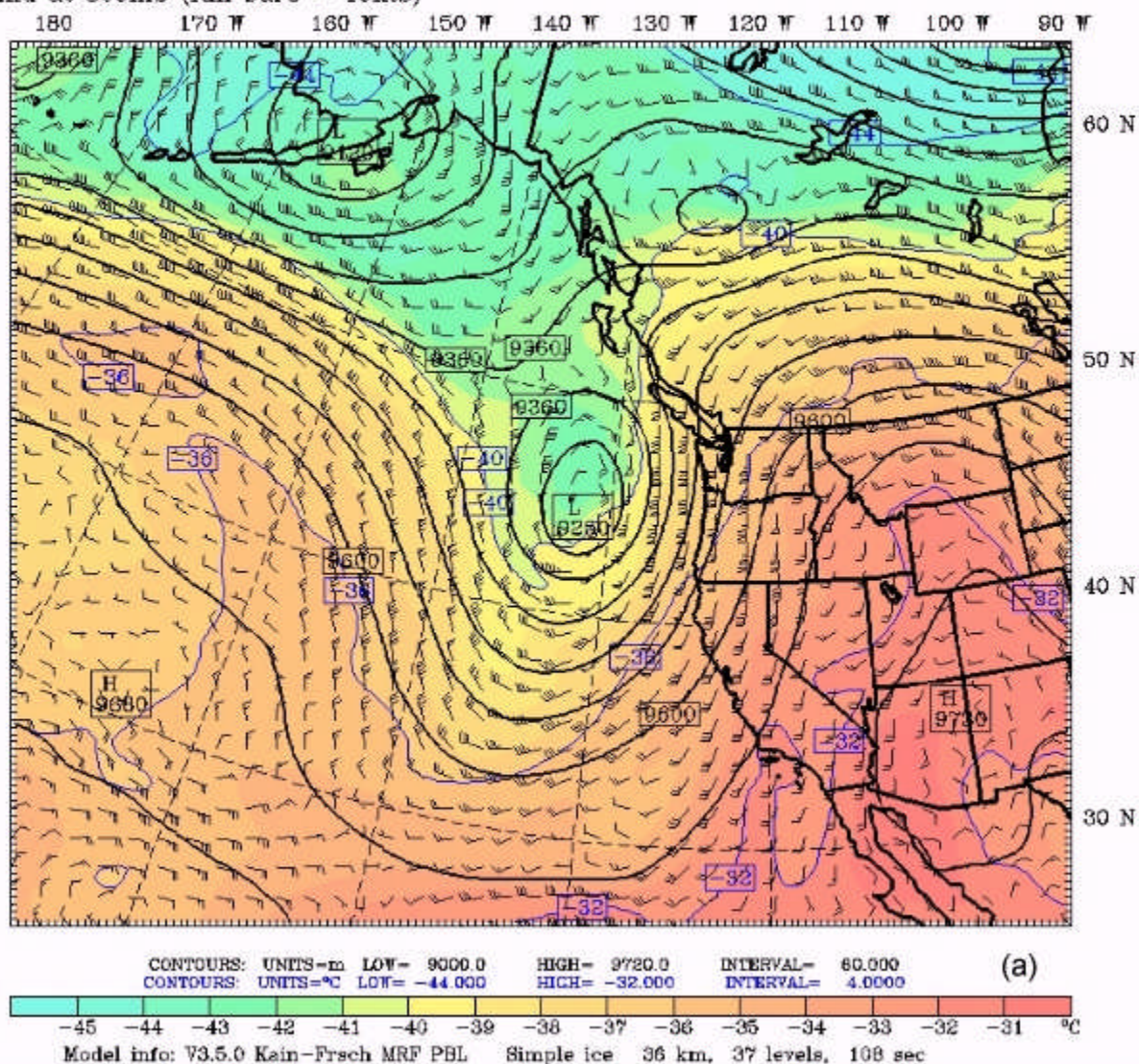


Figure 8a: MM5-ETA 300 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 36km Domain

Init: 12 UTC Sun 18 Jul 04

Fest: 6 h

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

Temperature at 500mb (°C)

Geopotential Height at 500mb (m)

Wind at 500mb (full barb = 10kts)

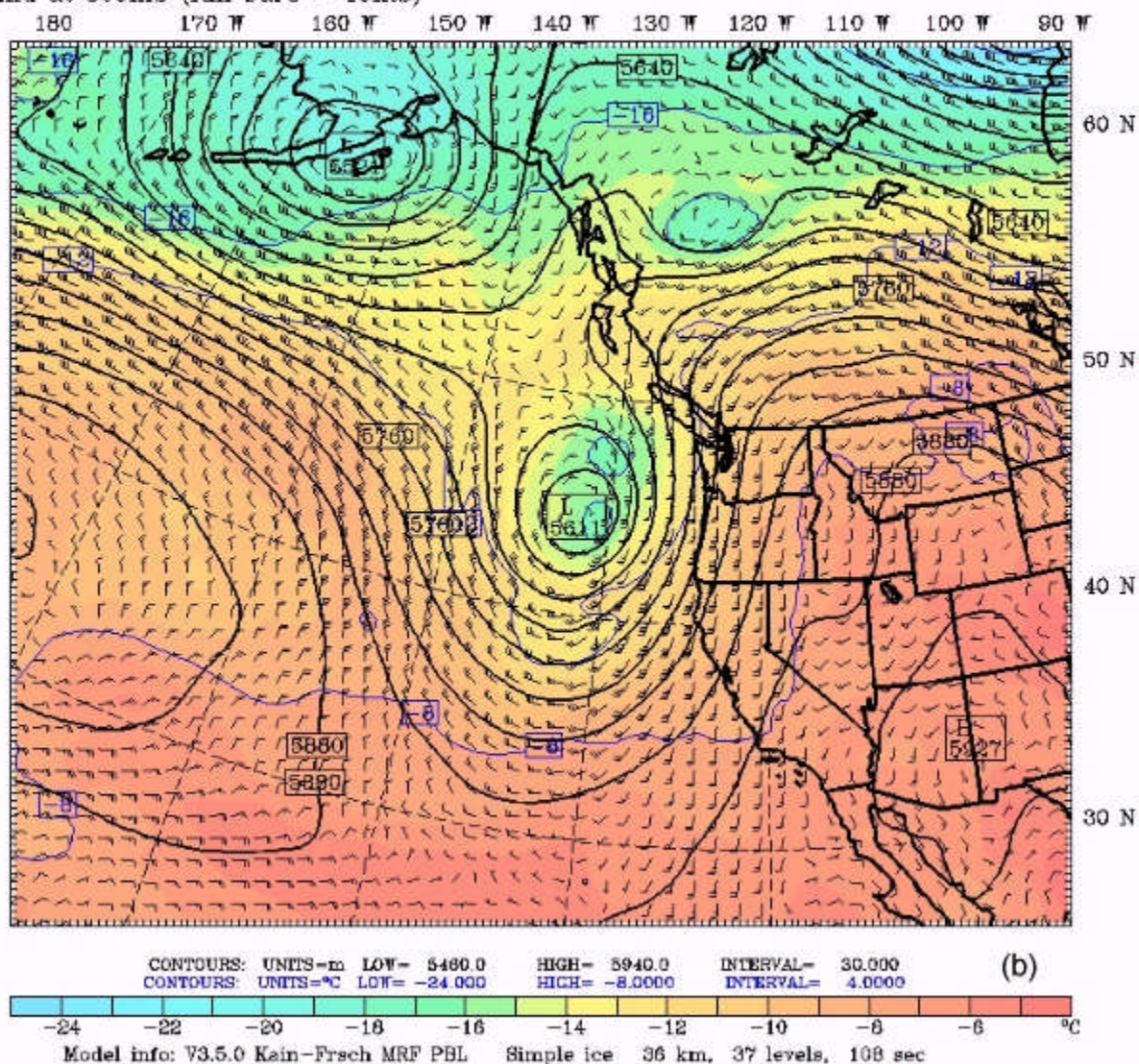


Figure 8b: MM5-ETA 500 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 6 h

300 mb wind speed (m/s)

Temperature at 300mb (°C)

Geopotential Height at 300mb (m)

Wind at 300mb (full barb = 10kts)

Init: 12 UTC Sun 18 Jul 04

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

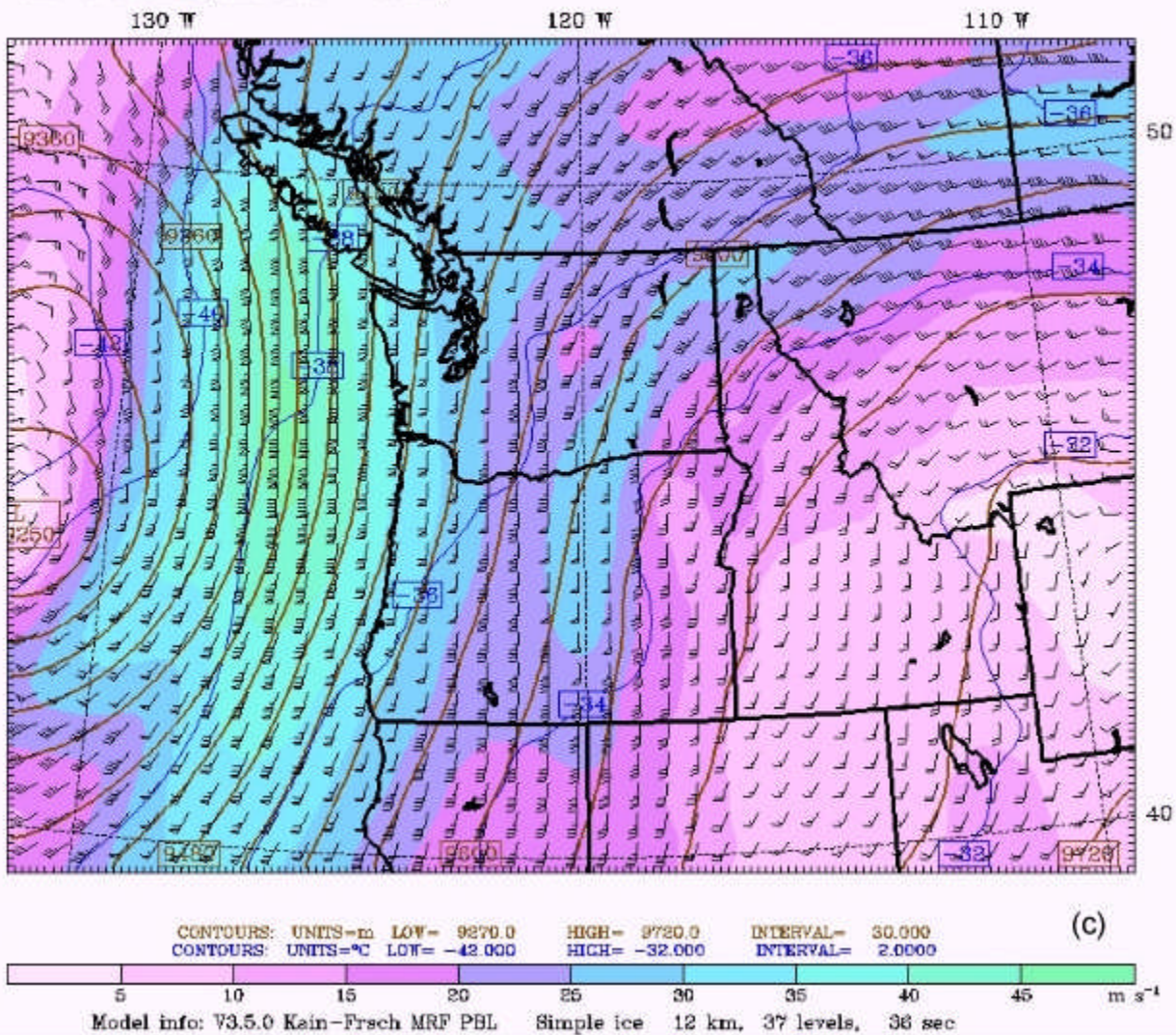


Figure 8c: MM5-ETA 300 mb wind speed (m s^{-1}), temperature ($^{\circ}\text{C}$), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 6 h

Absolute vorticity

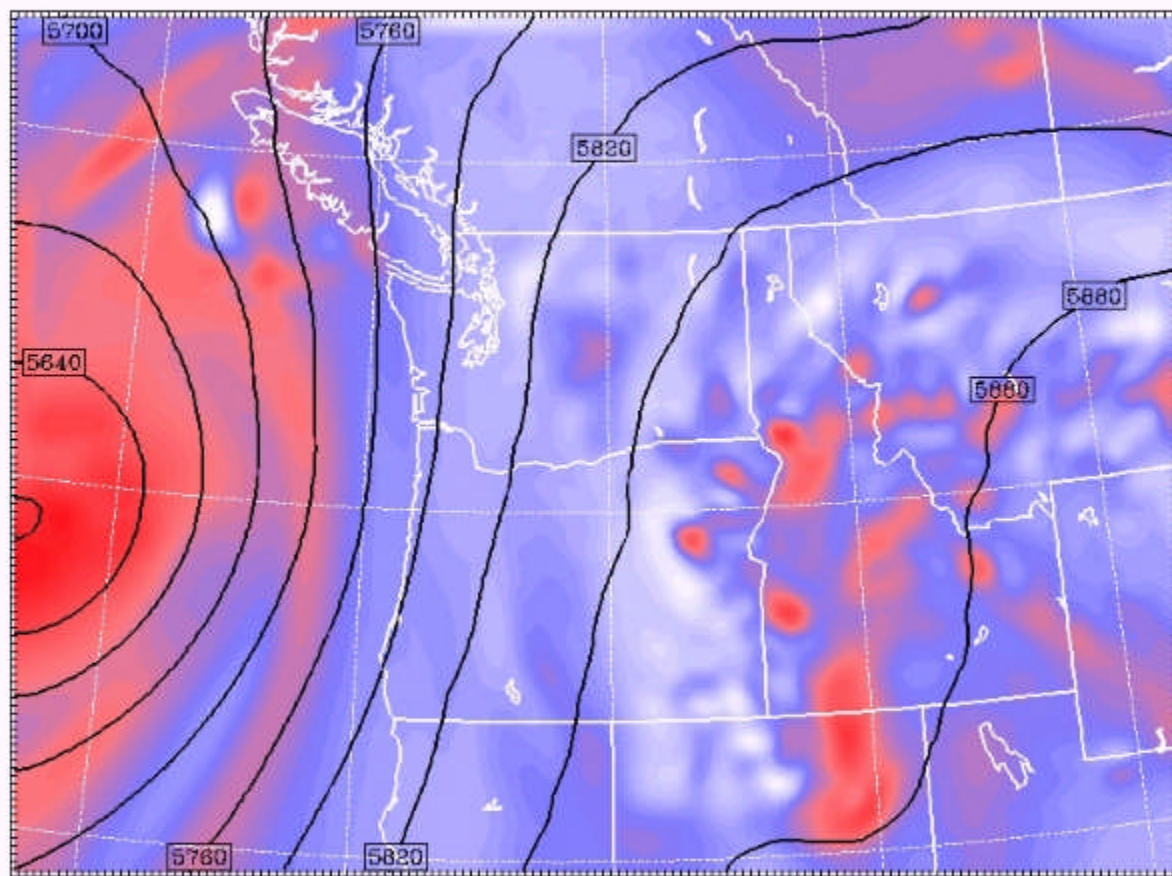
Geopotential Height at 500mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

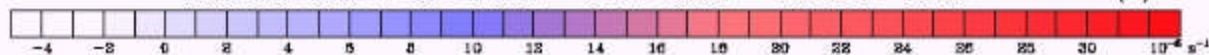
at pressure - 500 hPa

sm= 2



CONTOURS: UNITS=m LOW= 5610.0 HIGH= 5880.0 INTERVAL= 30.000

(d)



Model info: V3.5.0 Kain-Franch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 8d: MM5-ETA 500 mb absolute vorticity (s^{-1}) and geopotential height (m)

UW MM5-Eta 12km Domain

Fest: 6 h

Init: 12 UTC Sun 18 Jul 04

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

Temperature at 700mb (°C)

Geopotential Height at 700mb (m)

Wind at 700mb (full barb = 10kts)

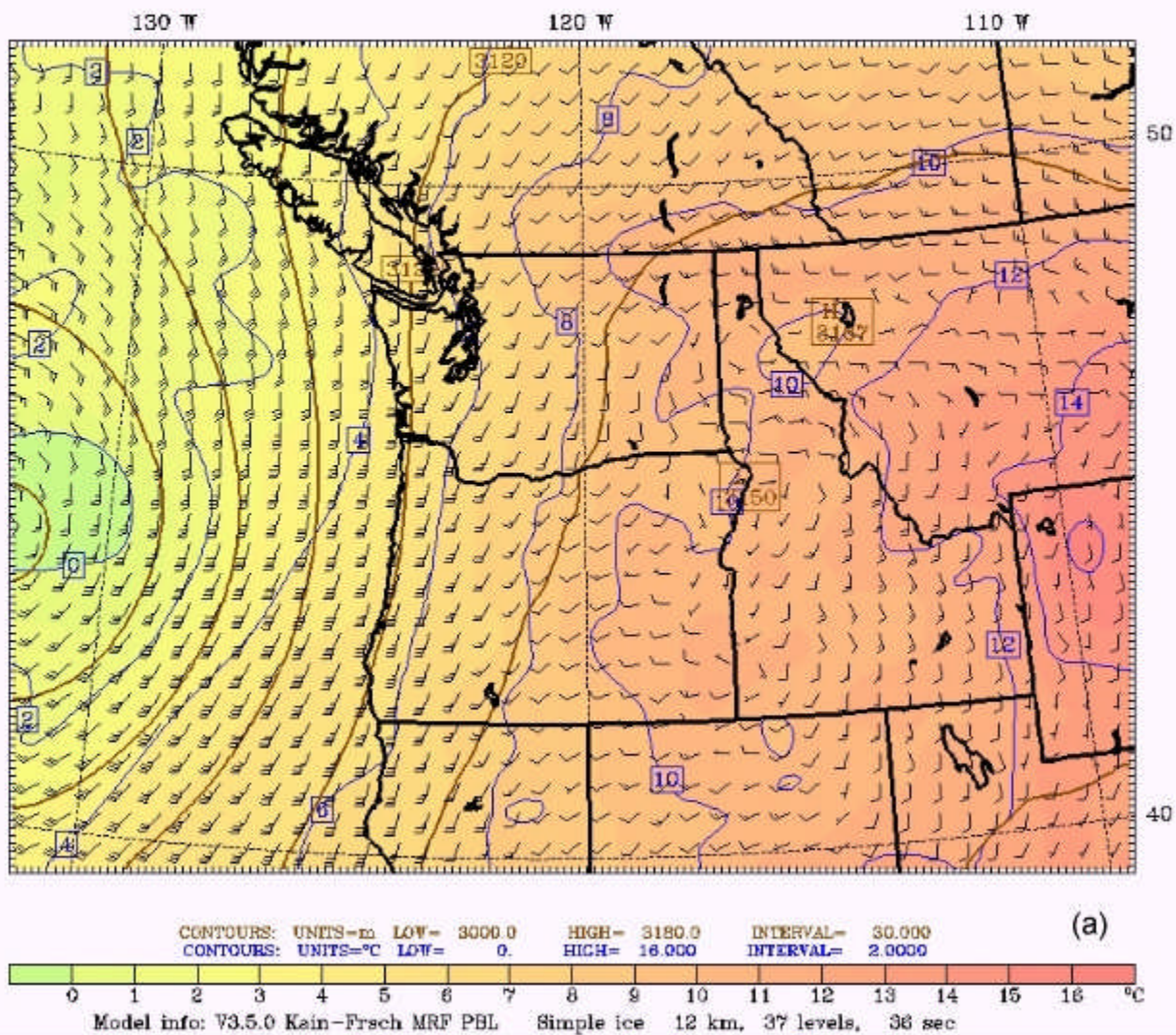


Figure 9a: MM5-ETA 700 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Init: 12 UTC Sun 18 Jul 04

Fest: 6 h

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

Temperature at 850mb (°C)

Geopotential Height at 850mb (m)

Wind at 850mb (full barb = 10kts)

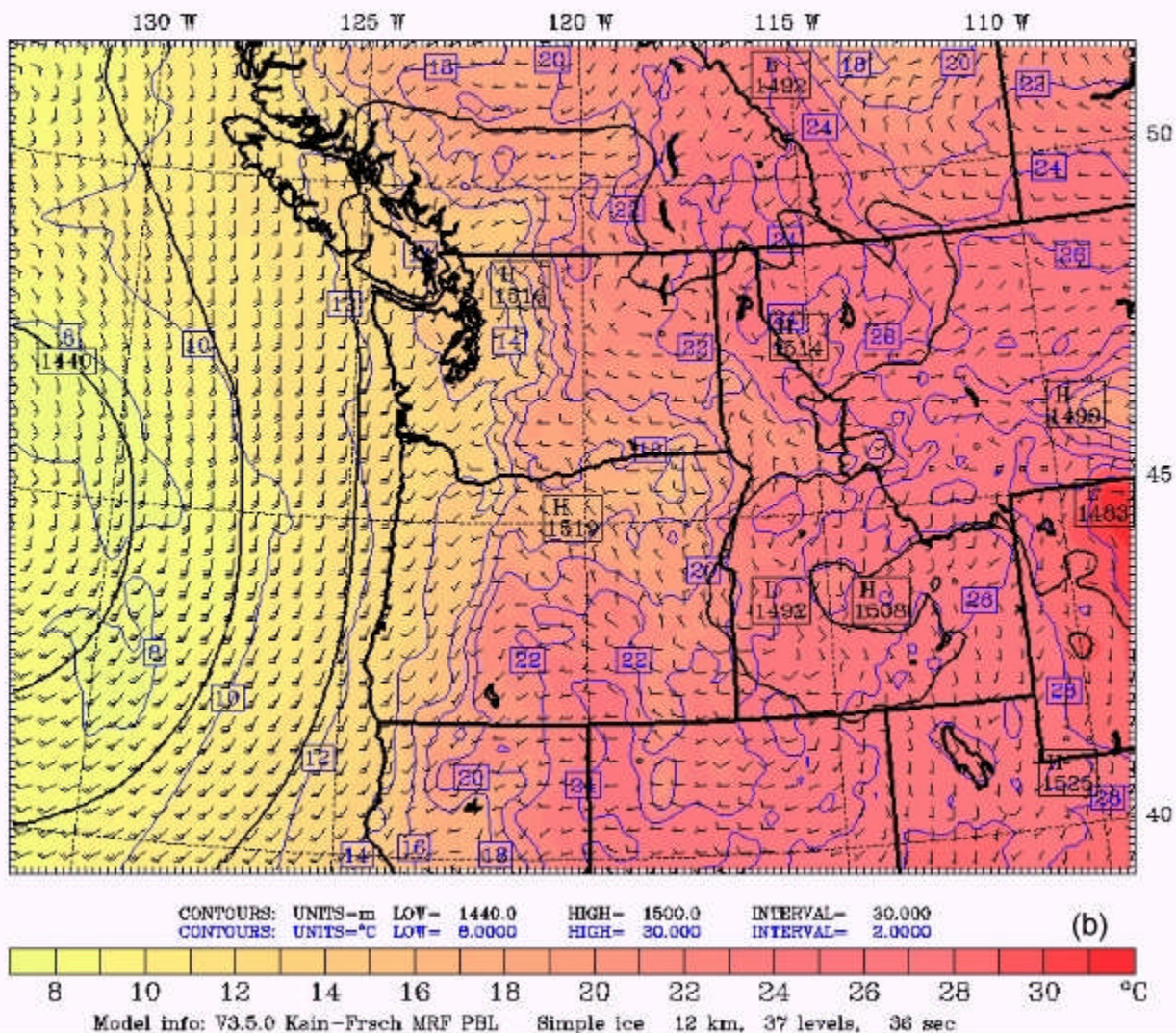


Figure 9b: MM5-ETA 850 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 6 h

Temperature at 925 mb (°C)

Sea Level Pressure (hPa)

Wind at 10m (full barb = 10kts)

Init: 12 UTC Sun 18 Jul 04

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

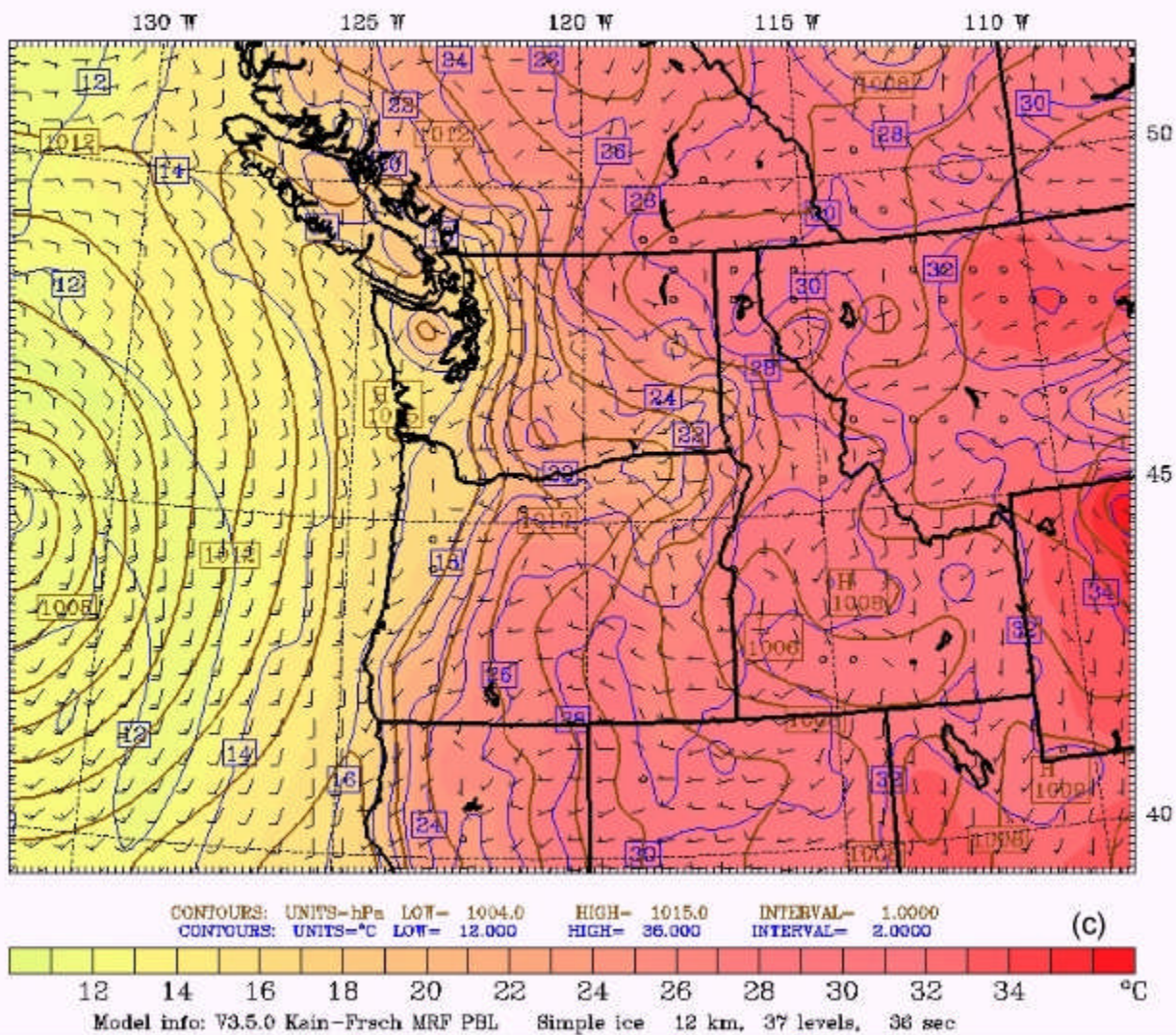


Figure 9c: MM5-ETA 925 mb temperature (°C), mean sea-level pressure (hPa), and 10 m wind (knots)

UW MM5-Eta 12km Domain
 Fest: 6 h
 Maximum CAPE (J/kg)
 Sea Level Pressure (hPa)

Init: 12 UTC Sun 18 Jul 04
 Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

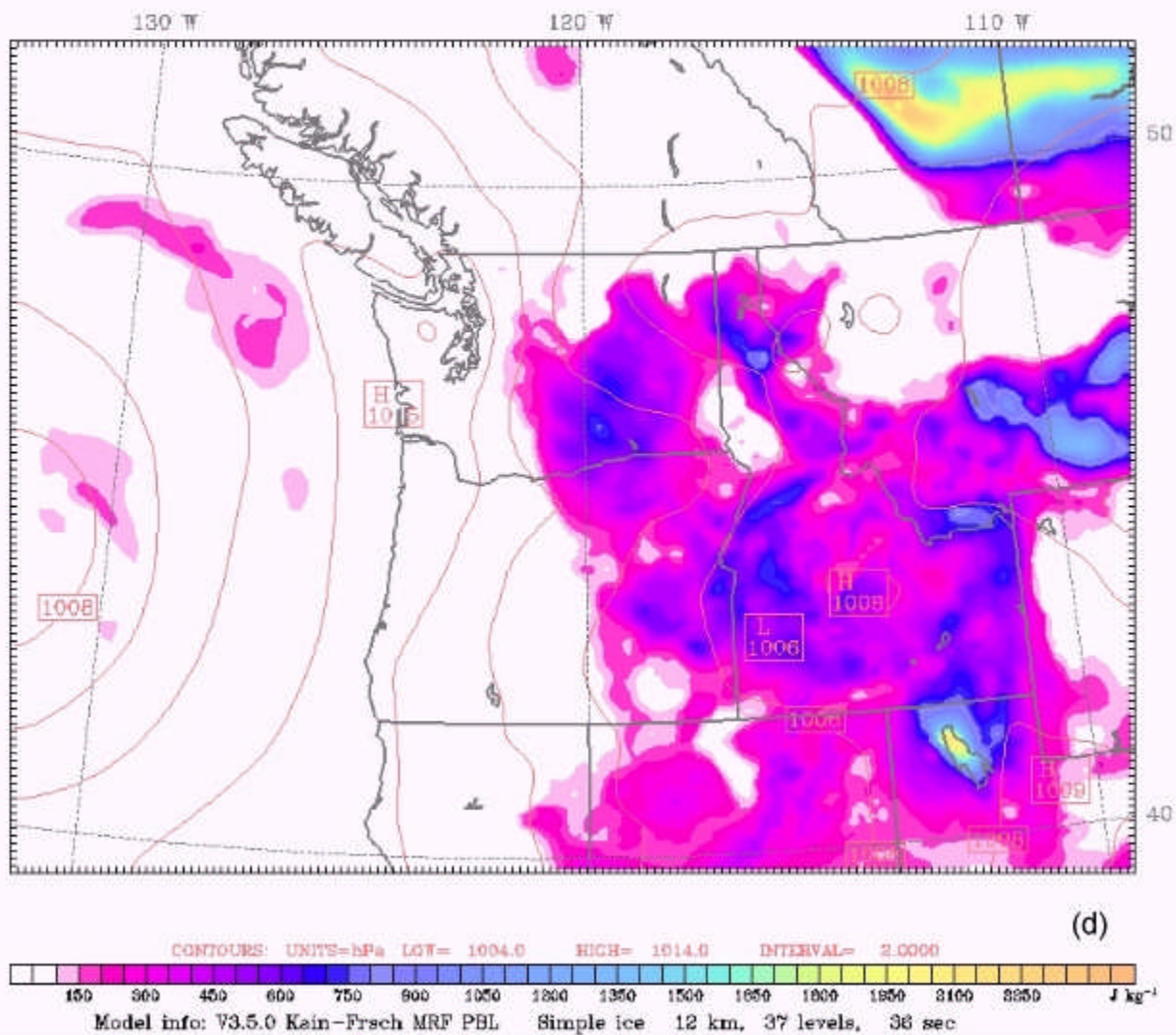


Figure 9d: MM5-ETA maximum CAPE (J kg⁻¹) and mean sea-level pressure (hPa)

Init: 12 UTC Sun 18 Jul 04

Fest: 6 h

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

Relative humidity (w.r.t. water)

at pressure = 500 hPa

Geopotential Height at 500mb (m)

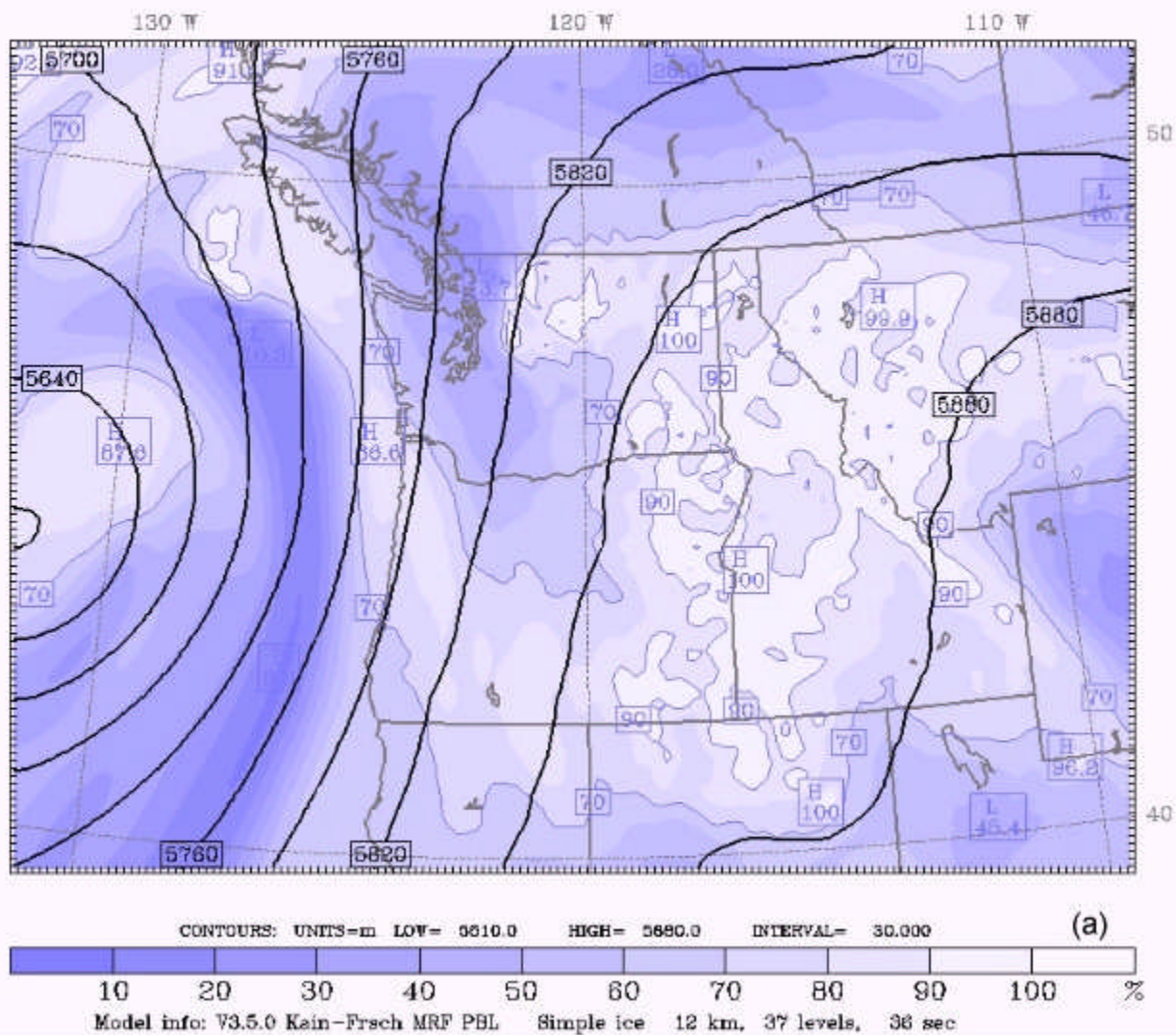


Figure 10a: MM5-ETA 500 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

Fest: 6 h

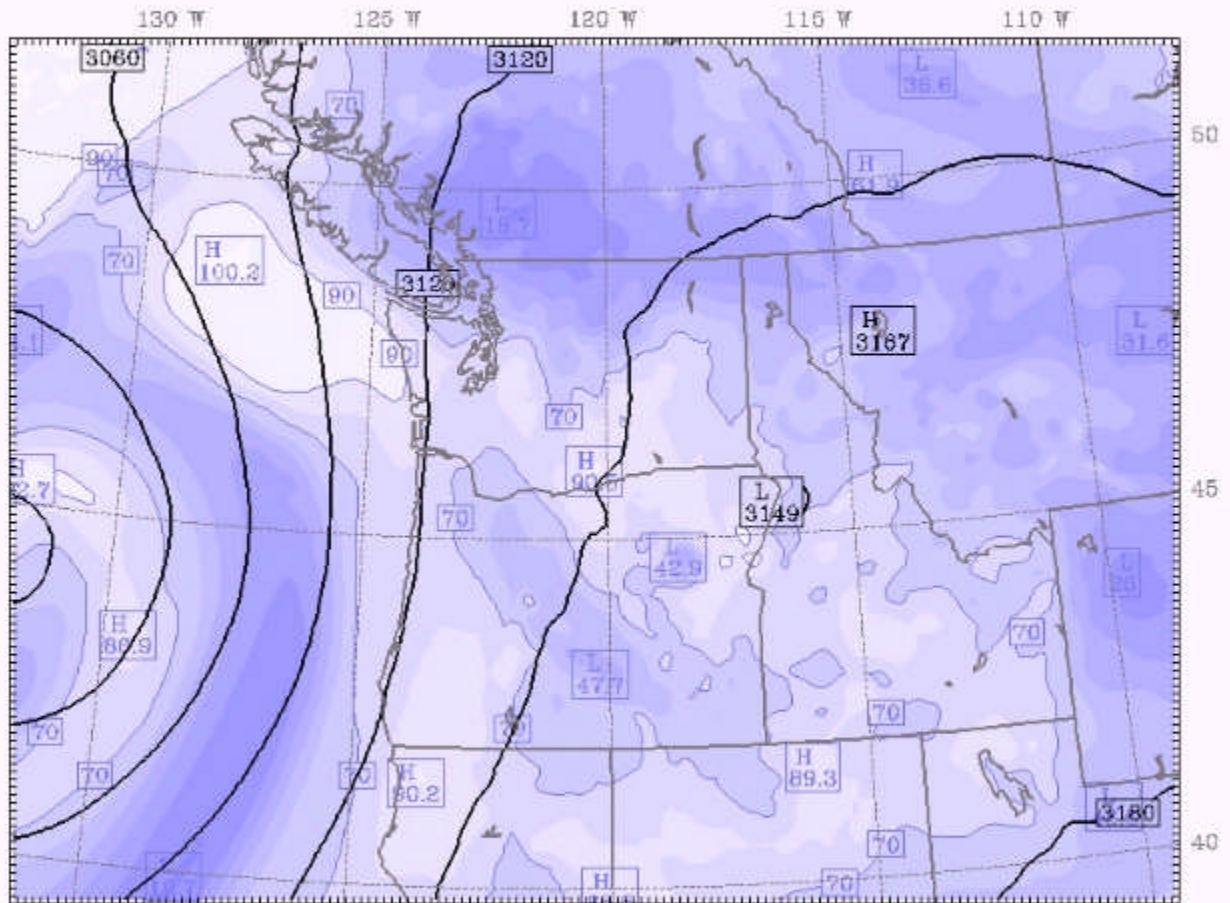
Relative humidity (w.r.t. water)

Geopotential Height at 700mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

at pressure - 700 hPa



CONTOURS: UNITS=m LOW= 3000.0 HIGH= 3180.0 INTERVAL= 30.000

(b)



Model info: V3.5.0 Kain-Frösch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 10b: MM5-ETA 700 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

Fest: 6 h

Relative humidity (w.r.t. water)

Geopotential Height at 850mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

at pressure - 850 hPa

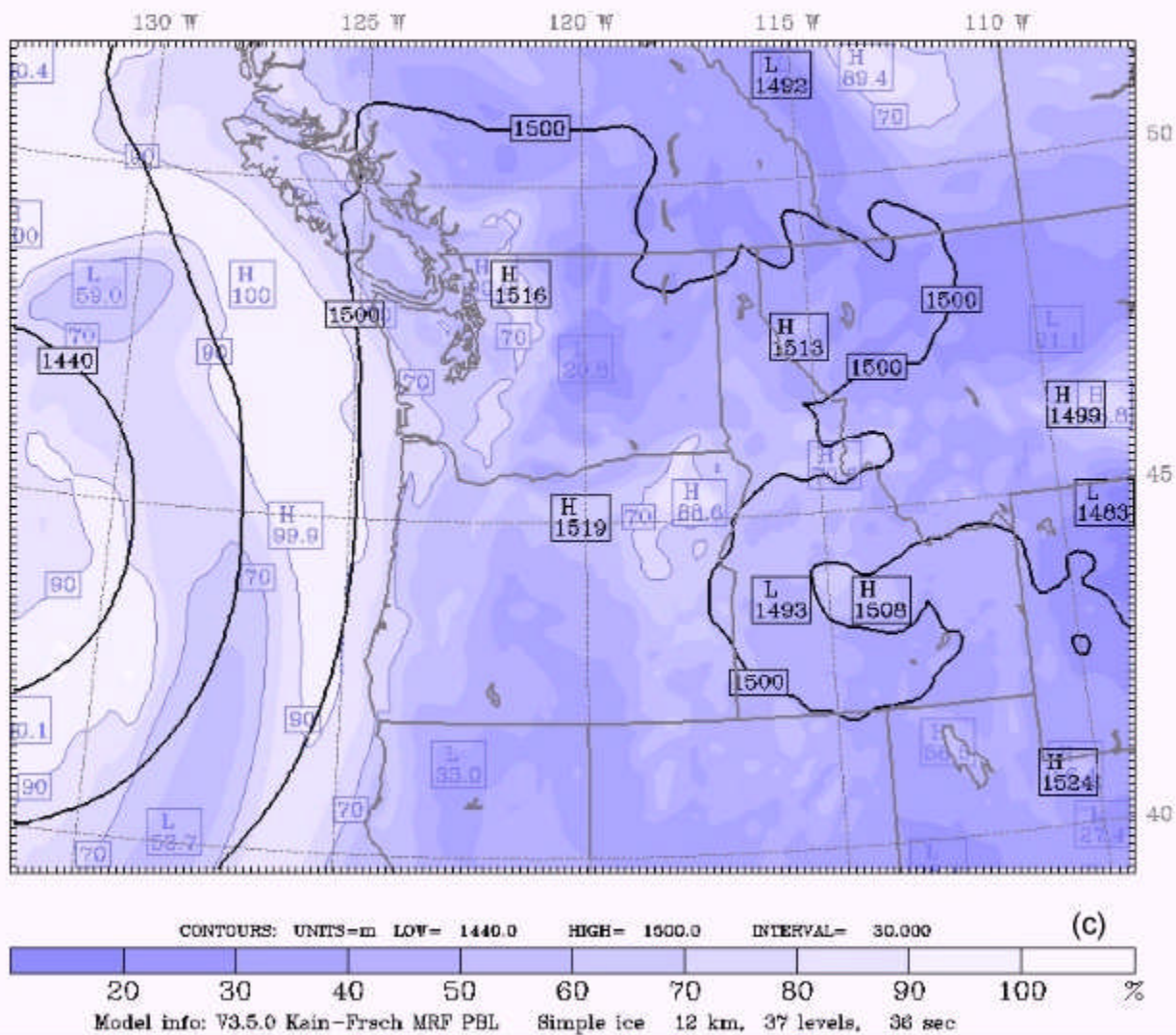


Figure 10c: MM5-ETA 850 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

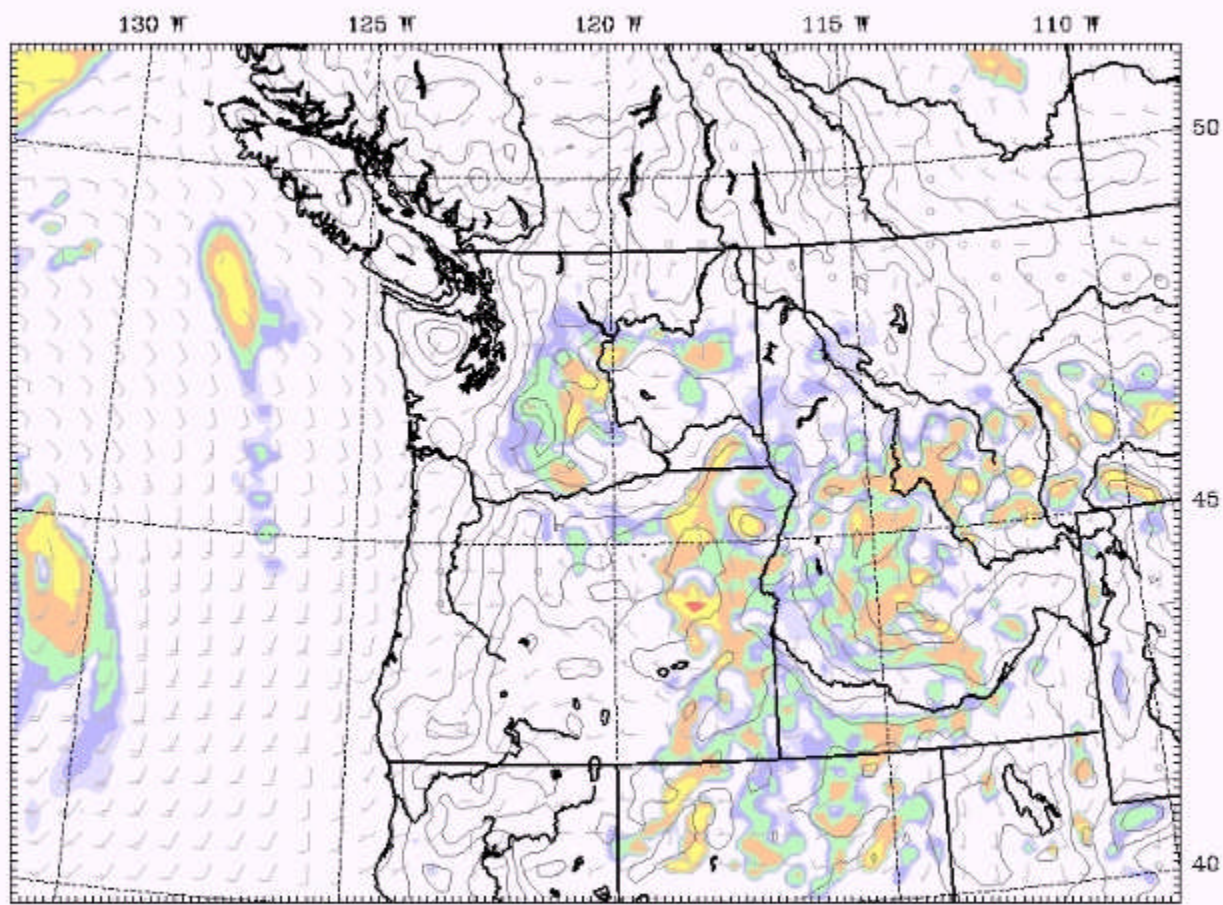
Init: 12 UTC Sun 18 Jul 04

Fest: 6 h

Valid: 18 UTC Sun 18 Jul 04 (11 PDT Sun 18 Jul 04)

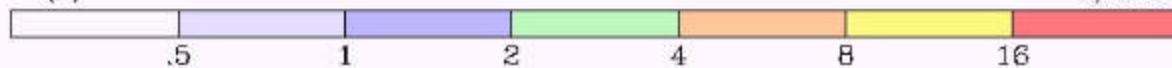
Total Precip in past 3 hrs (.01in)

Wind at 10m (full barb = 10kts)



(d)

1/100 inch



Model info: V3.5.0 Kain-Franch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 10d: MM5-ETA total precipitation in past 3 hours (inches) and 10 m wind (knots)

UW MM5-Eta 36km Domain

Init: 12 UTC Sun 18 Jul 04

Fest: 9 h

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

Temperature at 300mb (°C)

Geopotential Height at 300mb (m)

Wind at 300mb (full barb = 10kts)

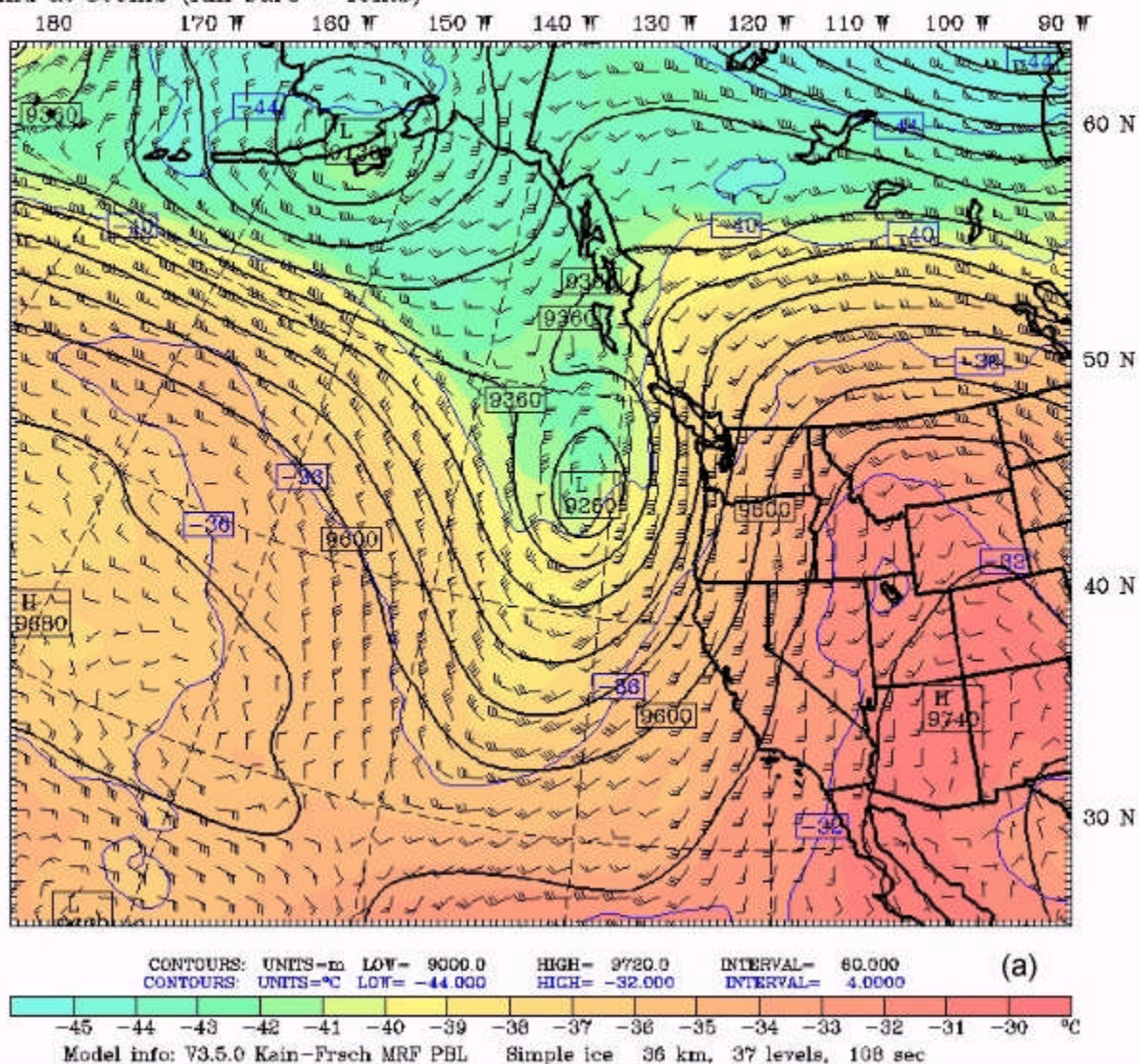


Figure 11a: MM5-ETA 300 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 36km Domain

Fest: 9 h

Init: 12 UTC Sun 18 Jul 04

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

Temperature at 500mb (°C)

Geopotential Height at 500mb (m)

Wind at 500mb (full barb = 10kts)

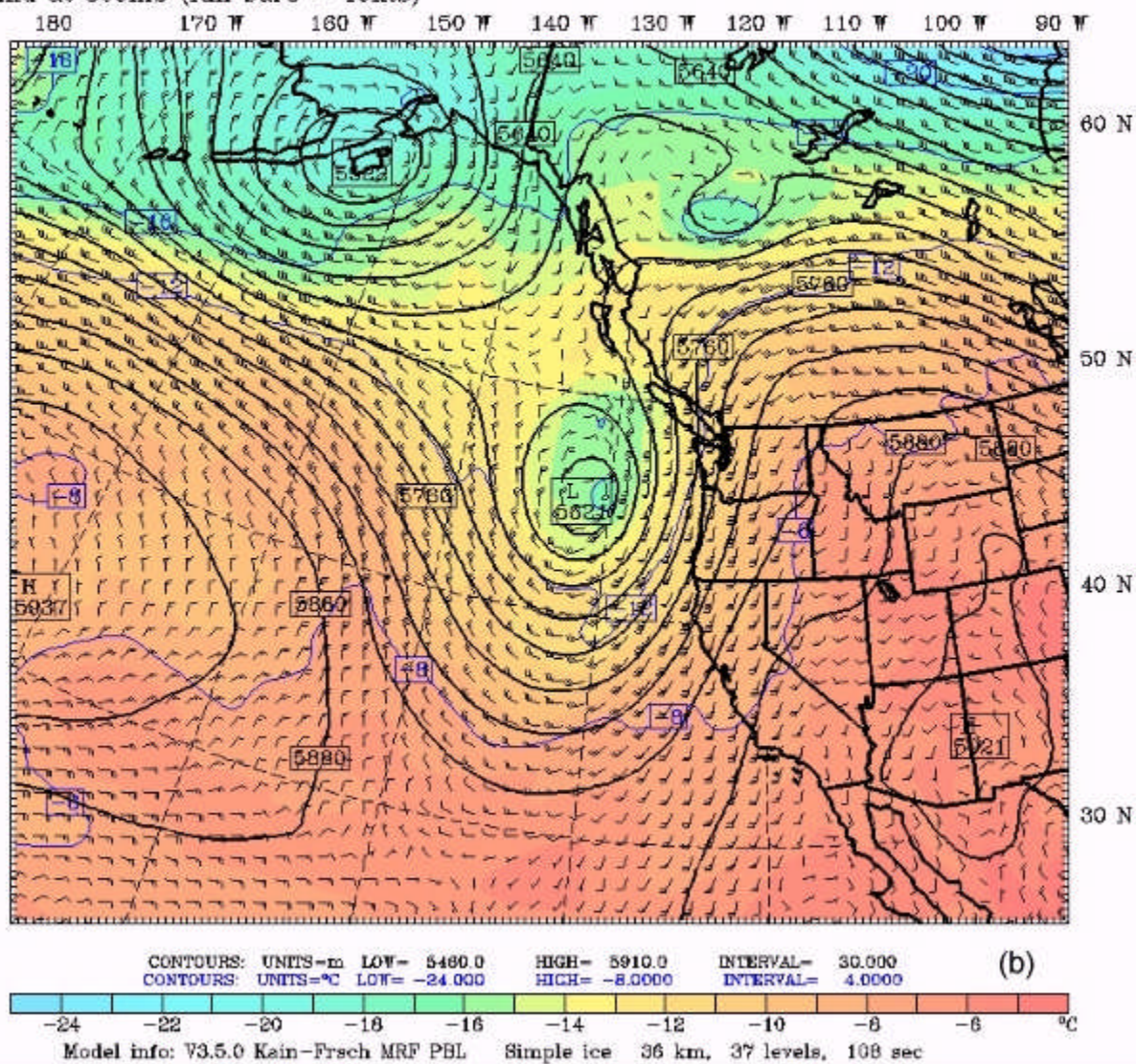


Figure 11b: MM5-ETA 500 mb temperature (°C), geopotential height (m), and wind (knots)

Init: 12 UTC Sun 18 Jul 04

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

300 mb wind speed (m/s)

Temperature at 300mb (°C)

Geopotential Height at 300mb (m)

Wind at 300mb (full barb = 10kts)

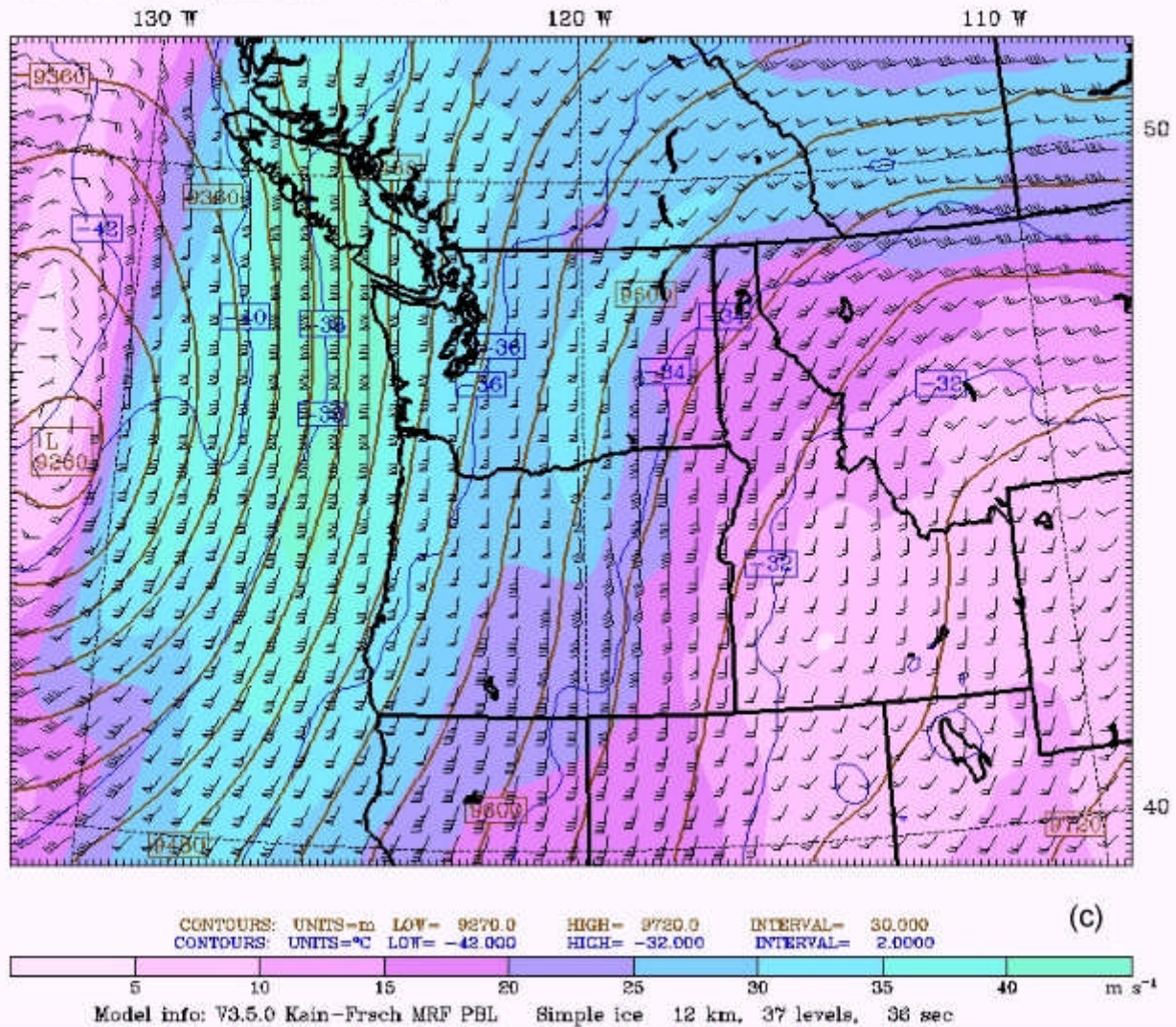


Figure 11c: MM5-ETA 300 mb wind speed ($\text{m}\cdot\text{s}^{-1}$), temperature ($^{\circ}\text{C}$), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 9 h

Absolute vorticity

Geopotential Height at 500mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

at pressure - 500 hPa

sm= 2

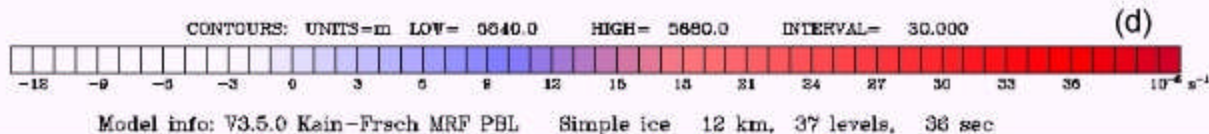
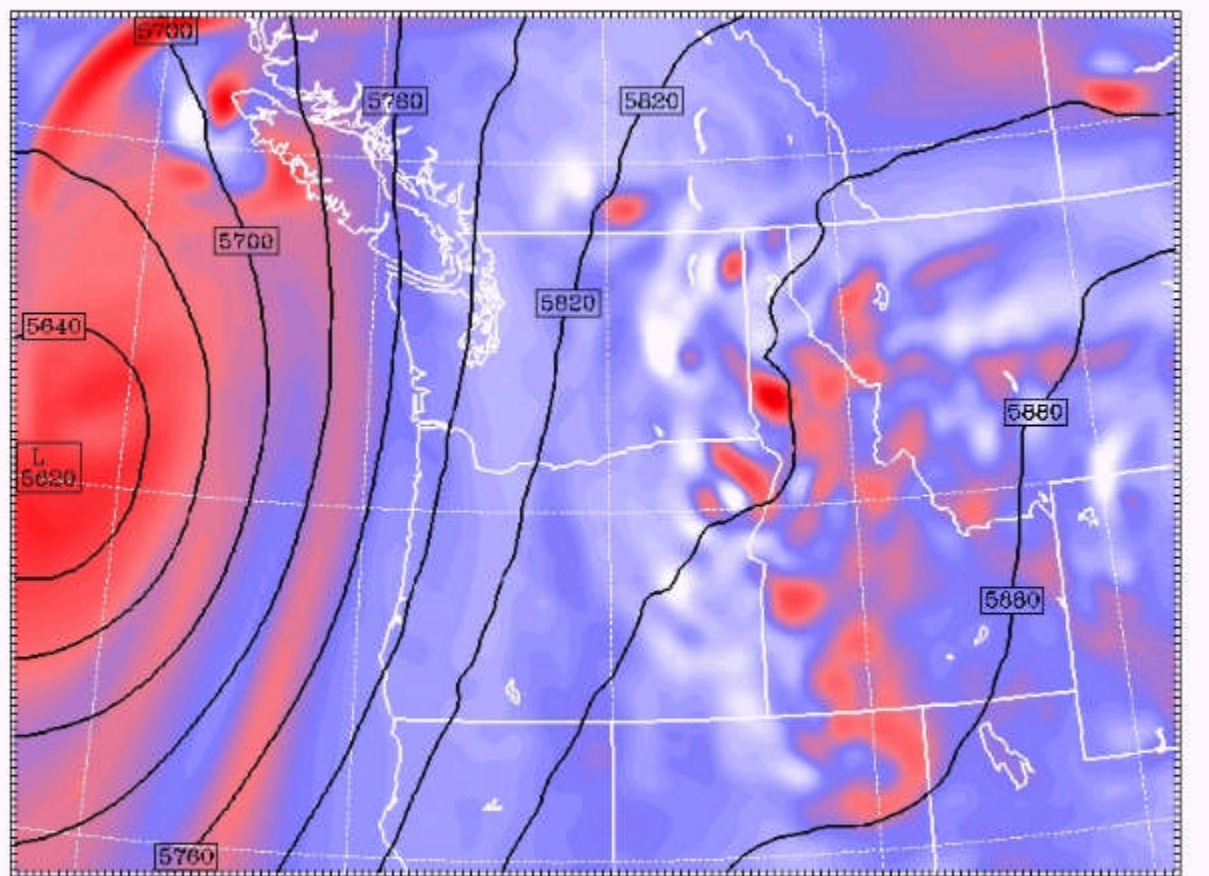


Figure 11d: MM5-ETA 500 mb absolute vorticity (s^{-1}) and geopotential height (m)

UW MM5-Eta 12km Domain

Fest: 9 h

Init: 12 UTC Sun 18 Jul 04

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

Temperature at 700mb (°C)

Geopotential Height at 700mb (m)

Wind at 700mb (full barb = 10kts)

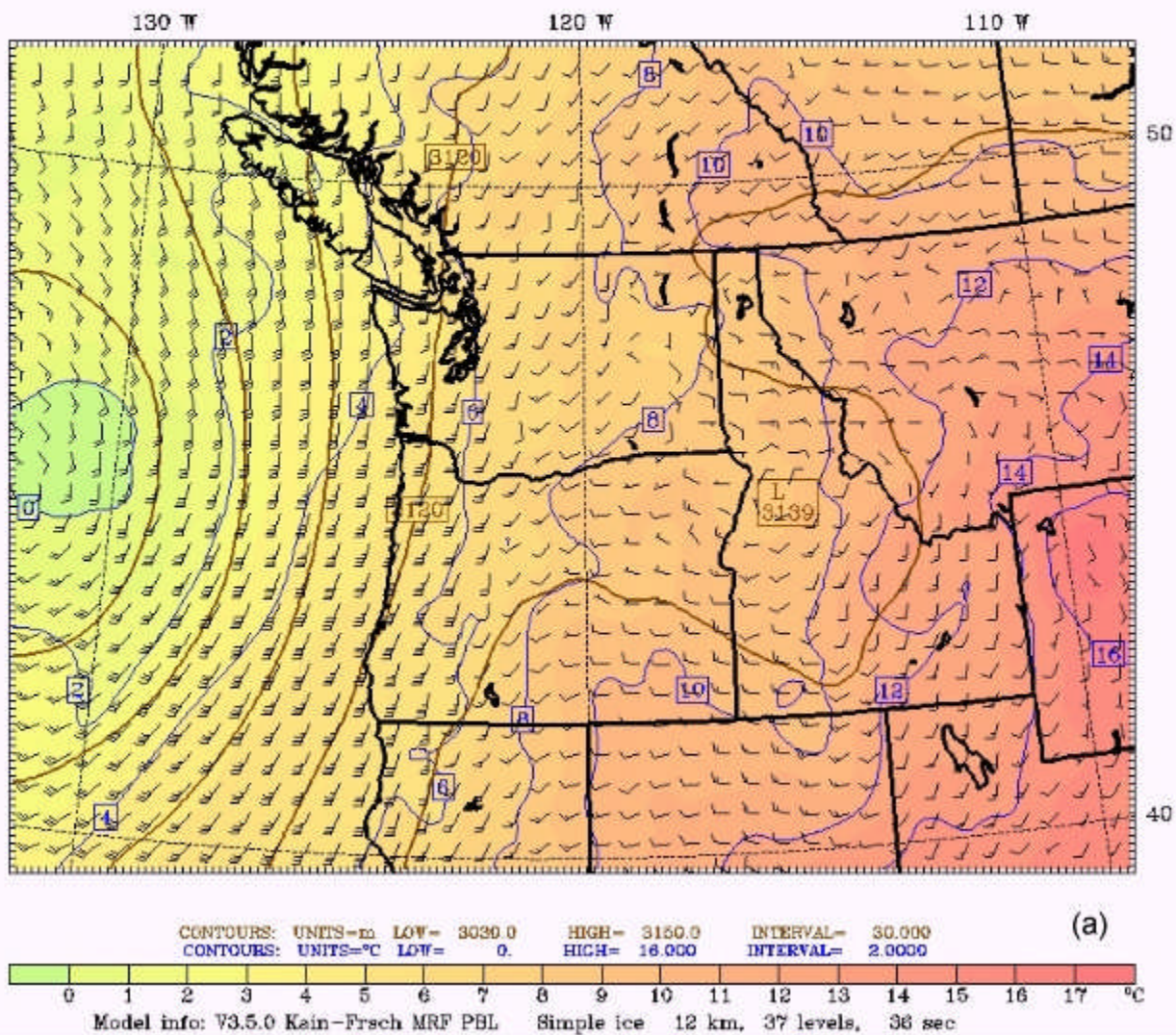


Figure 12a: MM5-ETA 700 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 9 h

Init: 12 UTC Sun 18 Jul 04

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

Temperature at 850mb (°C)

Geopotential Height at 850mb (m)

Wind at 850mb (full barb = 10kts)

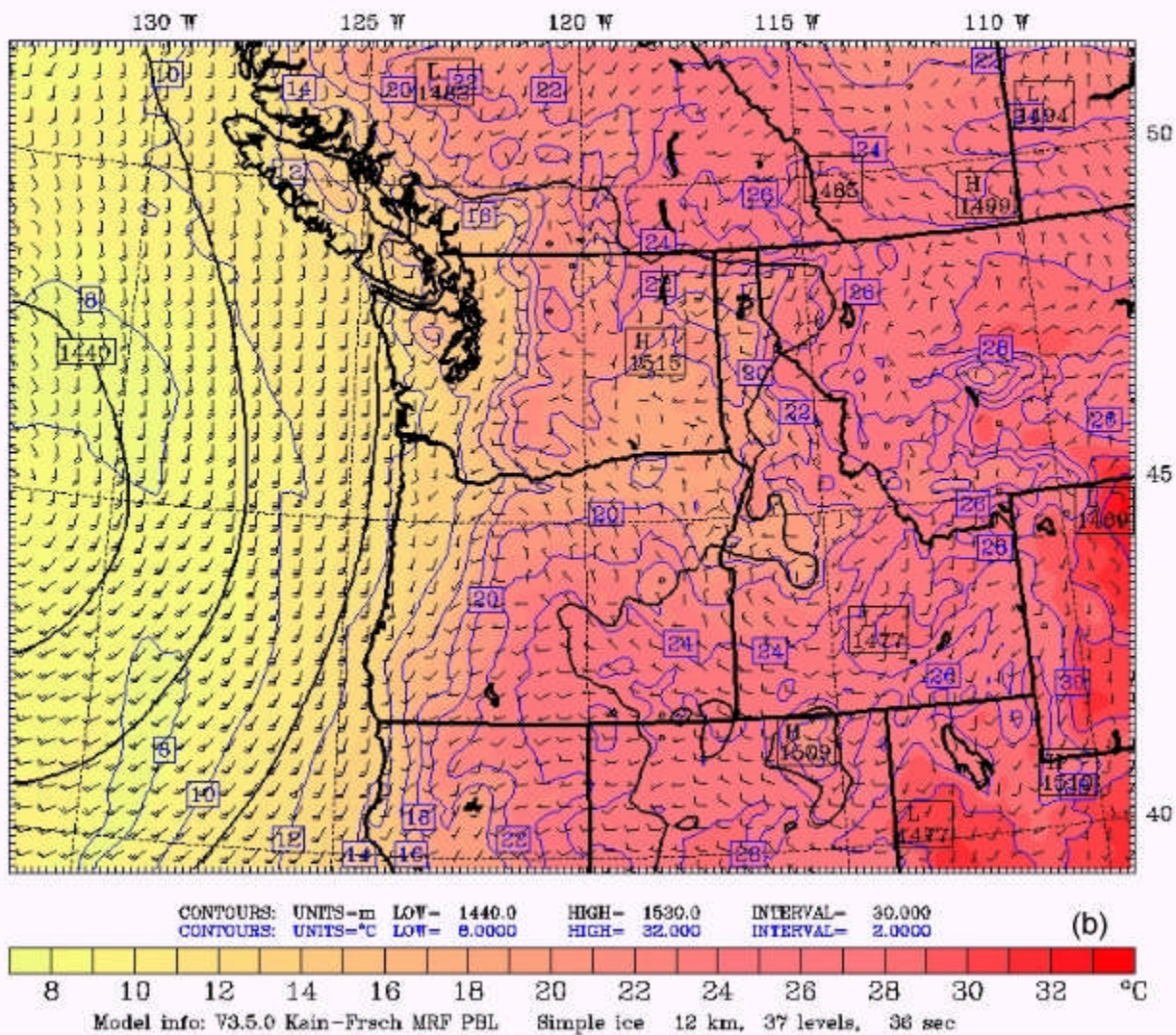


Figure 12b: MM5-ETA 850 mb temperature (°C), geopotential height (m), and wind (knots)

Init: 12 UTC Sun 18 Jul 04

Fest: 9 h

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

Temperature at 925 mb ($^{\circ}\text{C}$)

Sea Level Pressure (hPa)

Wind at 10m (full barb = 10kts)

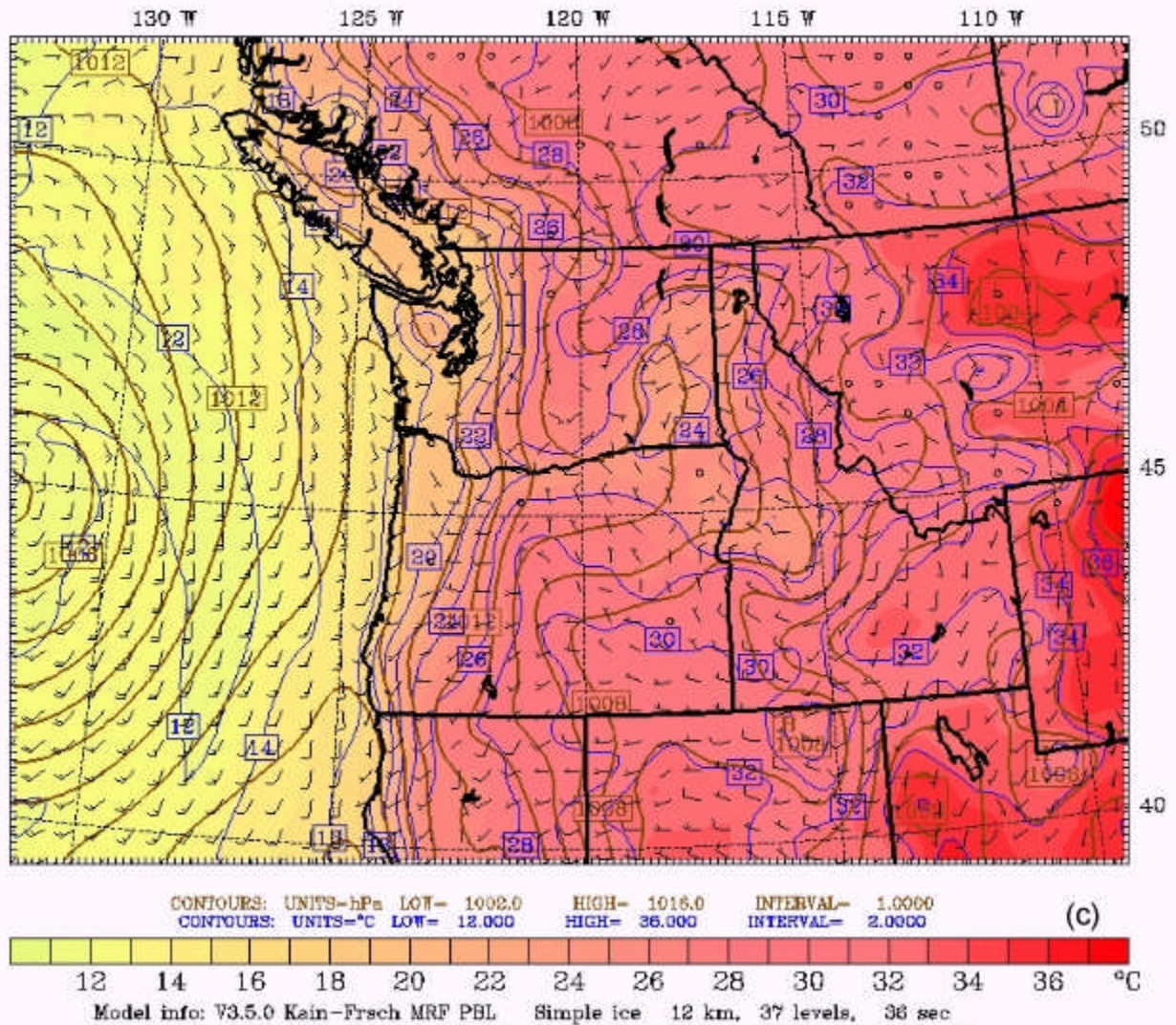


Figure 12c: MM5-ETA 925 mb temperature ($^{\circ}\text{C}$), mean sea-level pressure (hPa), and 10 m wind (knots)

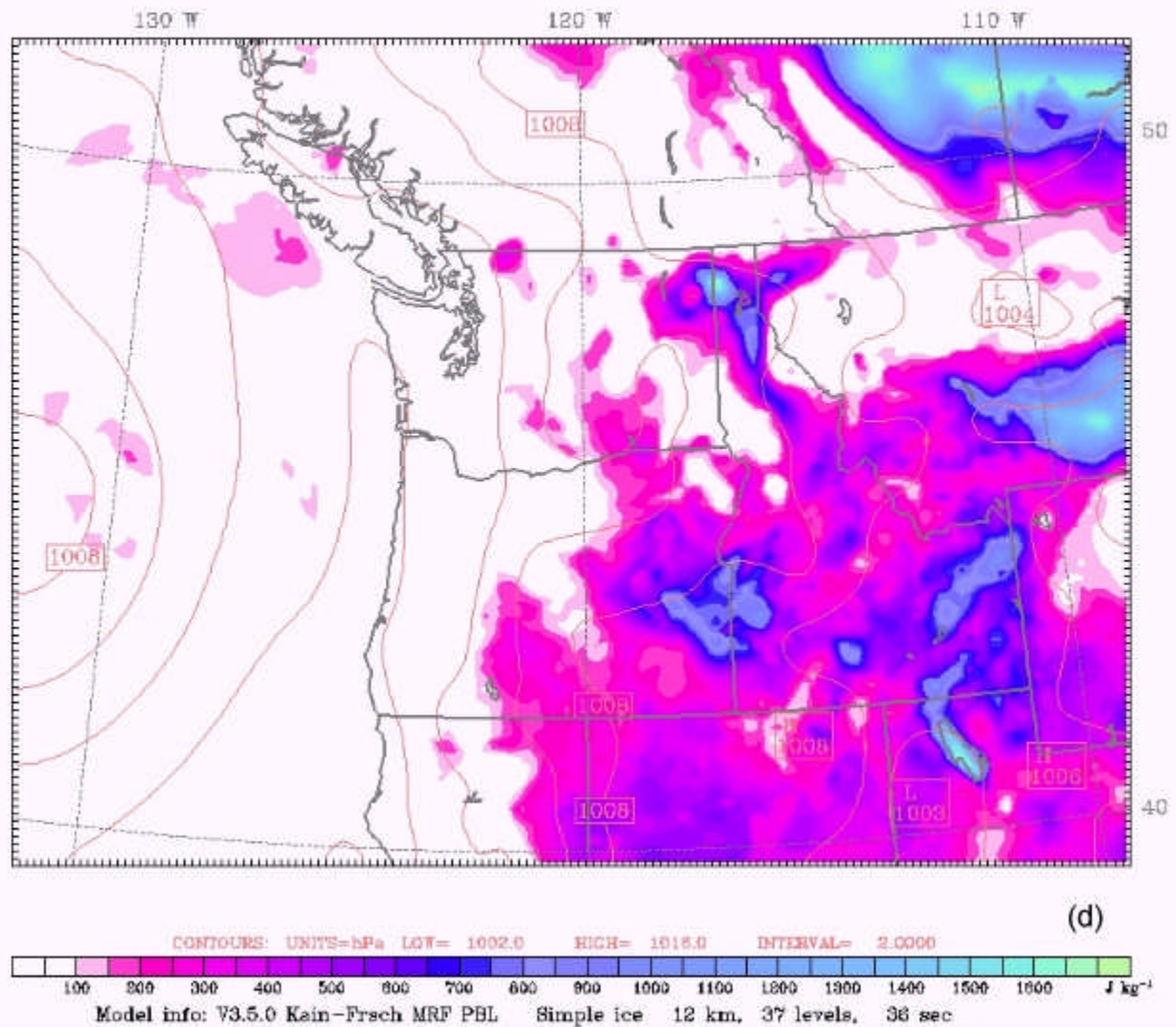
Init: 12 UTC Sun 18 Jul 04

Fest: 9 h

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

Maximum CAPE (J/kg)

Sea Level Pressure (hPa)



UW MM5-Eta 12km Domain

Fcst: 9 h

Relative humidity (w.r.t. water)

Geopotential Height at 500mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

at pressure - 500 hPa

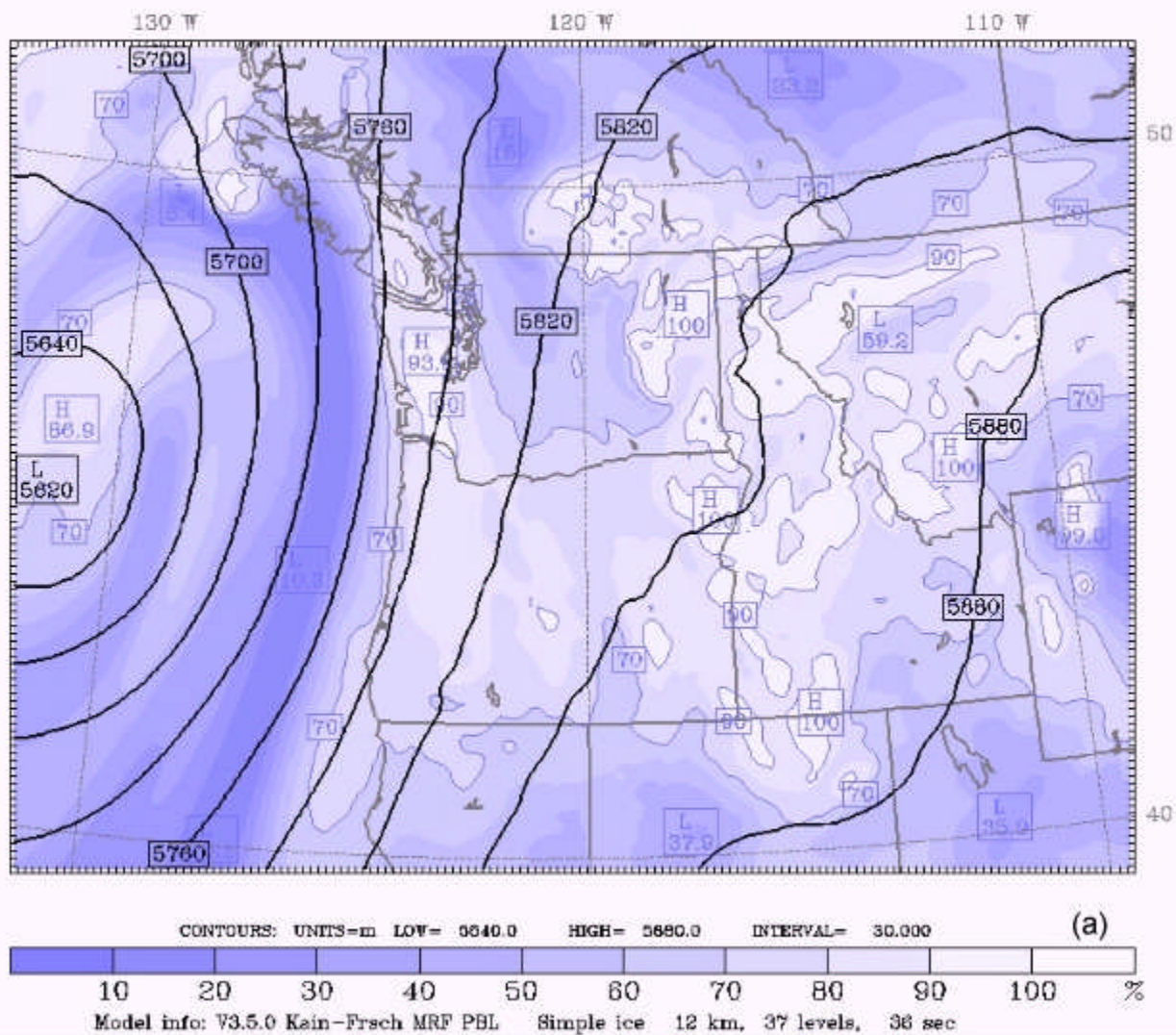


Figure 13a: MM5-ETA 500 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

Fest: 9 h

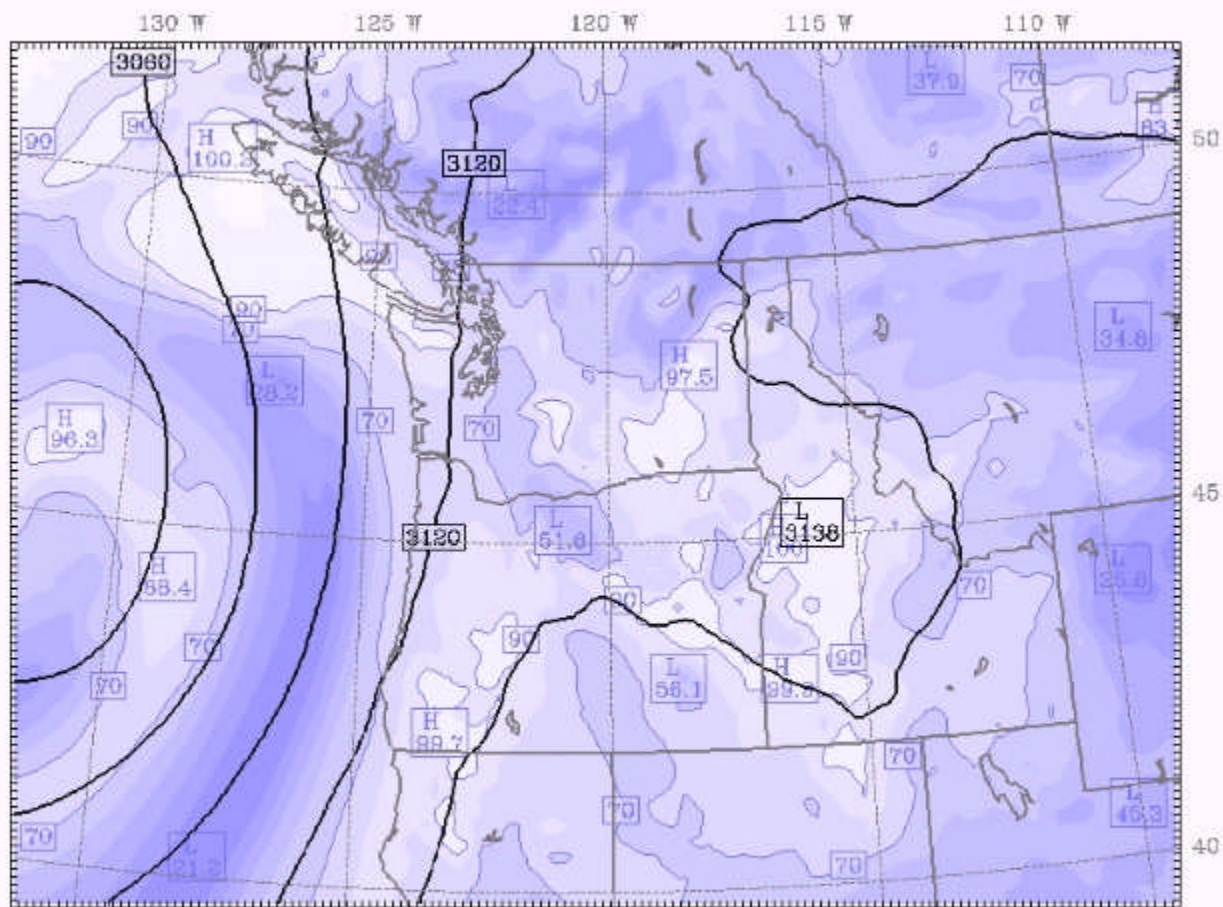
Relative humidity (w.r.t. water)

Geopotential Height at 700mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

at pressure - 700 hPa



CONTOURS: UNITS=m LOW= 3080.0 HIGH= 3160.0 INTERVAL= 30.000

(b)



Model info: V3.5.0 Kain-Franch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 13b: MM5-ETA 700 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

Fest: 9 h

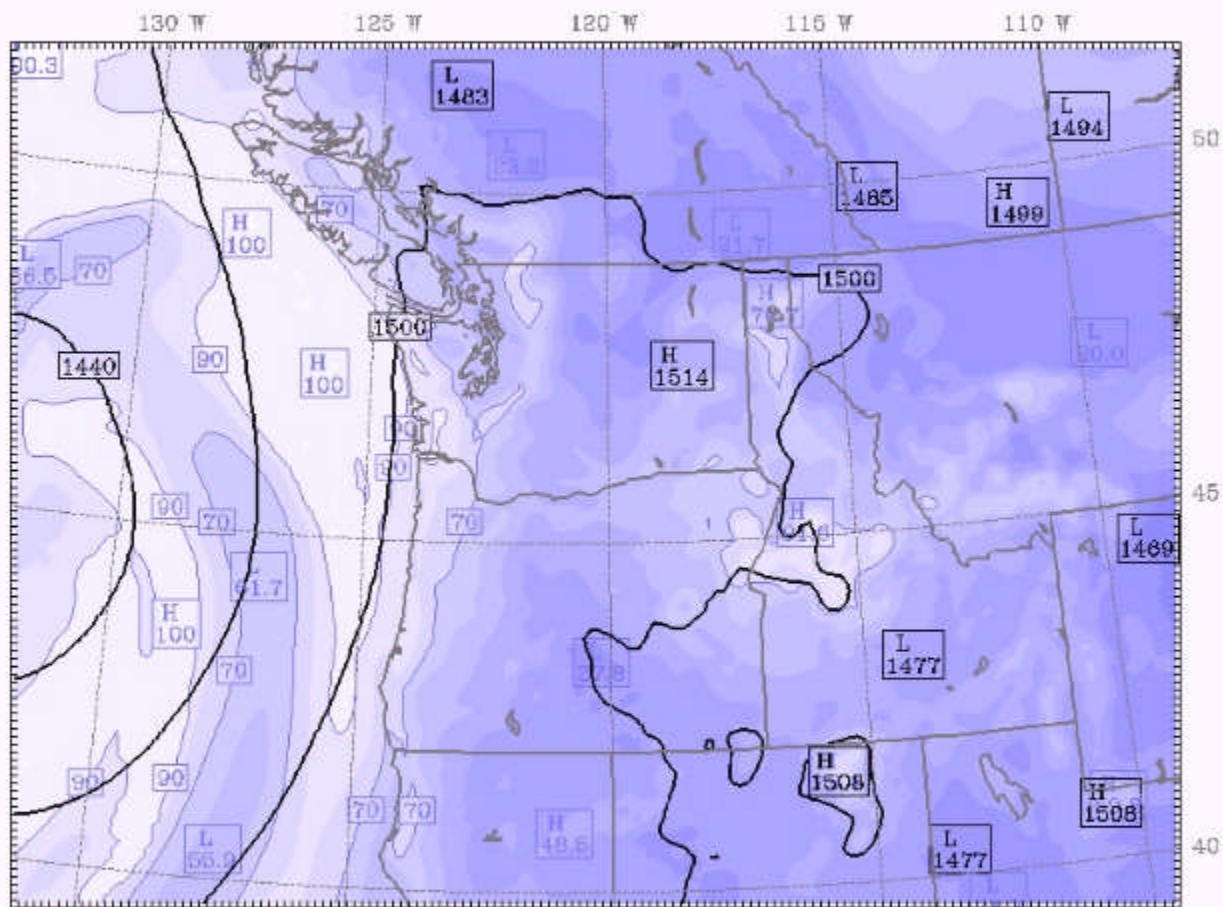
Relative humidity (w.r.t. water)

Geopotential Height at 850mb (m)

Init: 12 UTC Sun 18 Jul 04

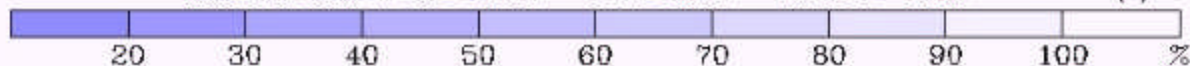
Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

at pressure - 850 hPa



CONTOURS: UNITS=m LOW= 1440.0 HIGH= 1500.0 INTERVAL= 30.000

(c)



Model info: V3.5.0 Kain-Franch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 13c: MM5-ETA 850 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

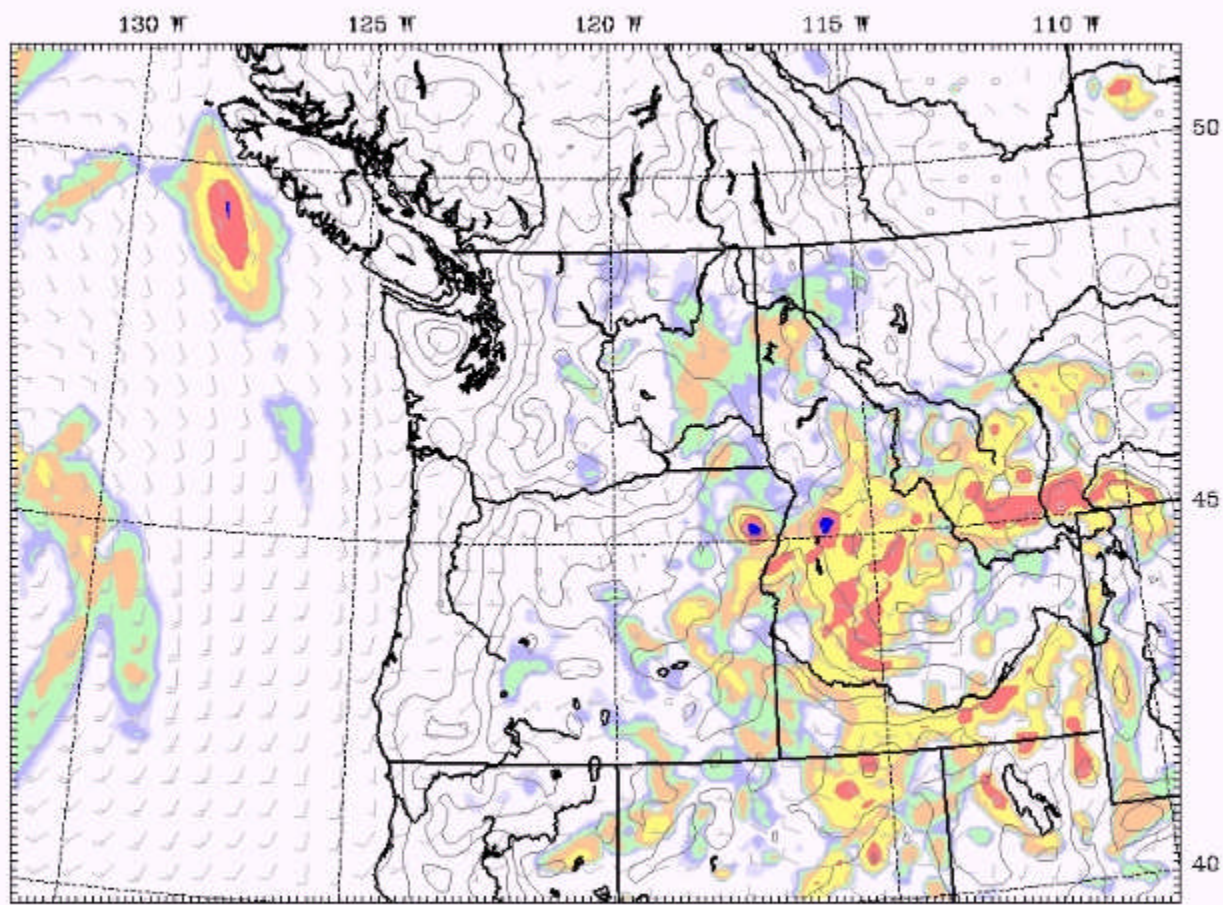
Init: 12 UTC Sun 18 Jul 04

Fest: 9 h

Valid: 21 UTC Sun 18 Jul 04 (14 PDT Sun 18 Jul 04)

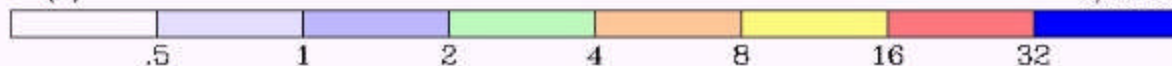
Total Precip in past 3 hrs (.01in)

Wind at 10m (full barb = 10kts)



(d)

1/100 inch



Model info: V3.5.0 Kain-Frisch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 13d: MM5-ETA total precipitation in past 3 hours (inches) and 10 m wind (knots)

UW MM5-Eta 36km Domain

Init: 12 UTC Sun 18 Jul 04

Fest: 12 h

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

Temperature at 300mb (°C)

Geopotential Height at 300mb (m)

Wind at 300mb (full barb = 10kts)

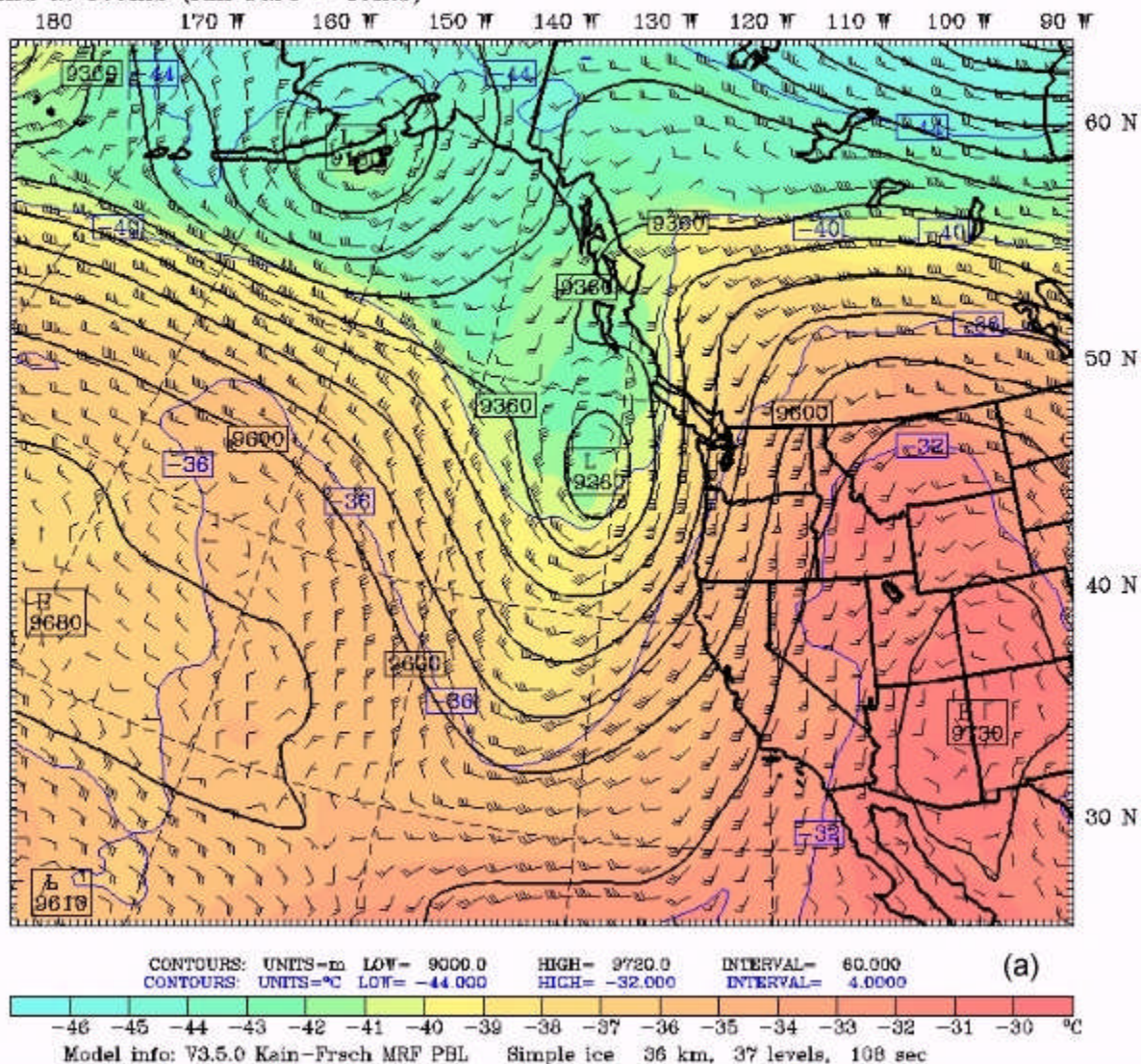


Figure 14a: MM5-ETA 300 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 36km Domain

Init: 12 UTC Sun 18 Jul 04

Fest: 12 h

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

Temperature at 500mb (°C)

Geopotential Height at 500mb (m)

Wind at 500mb (full barb = 10kts)

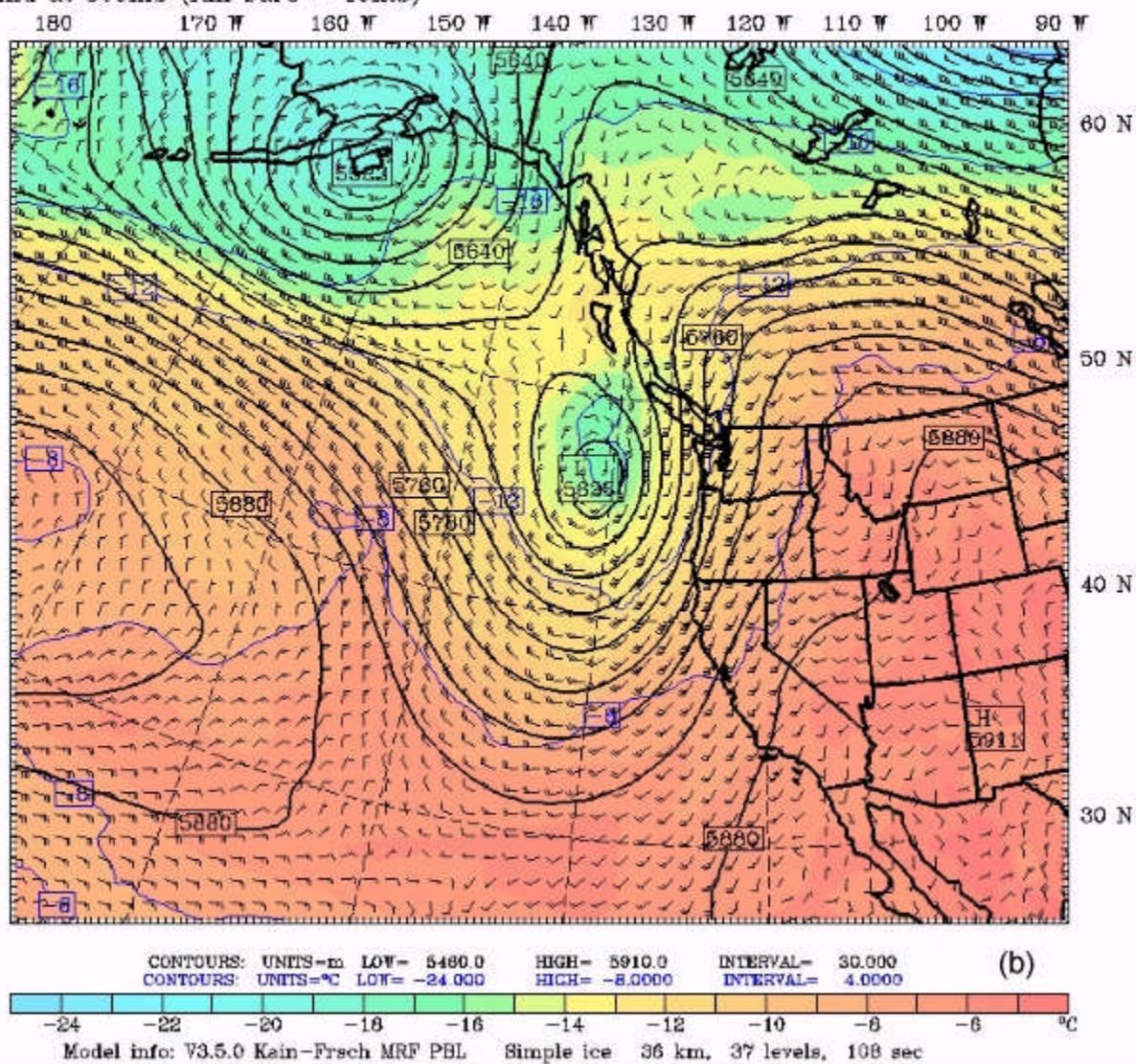


Figure 14b: MM5-ETA 500 mb temperature (°C), geopotential height (m), and wind (knots)

Init: 12 UTC Sun 18 Jul 04

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

300 mb wind speed (m/s)

Temperature at 300mb (°C)

Geopotential Height at 300mb (m)

Wind at 300mb (full barb = 10kts)

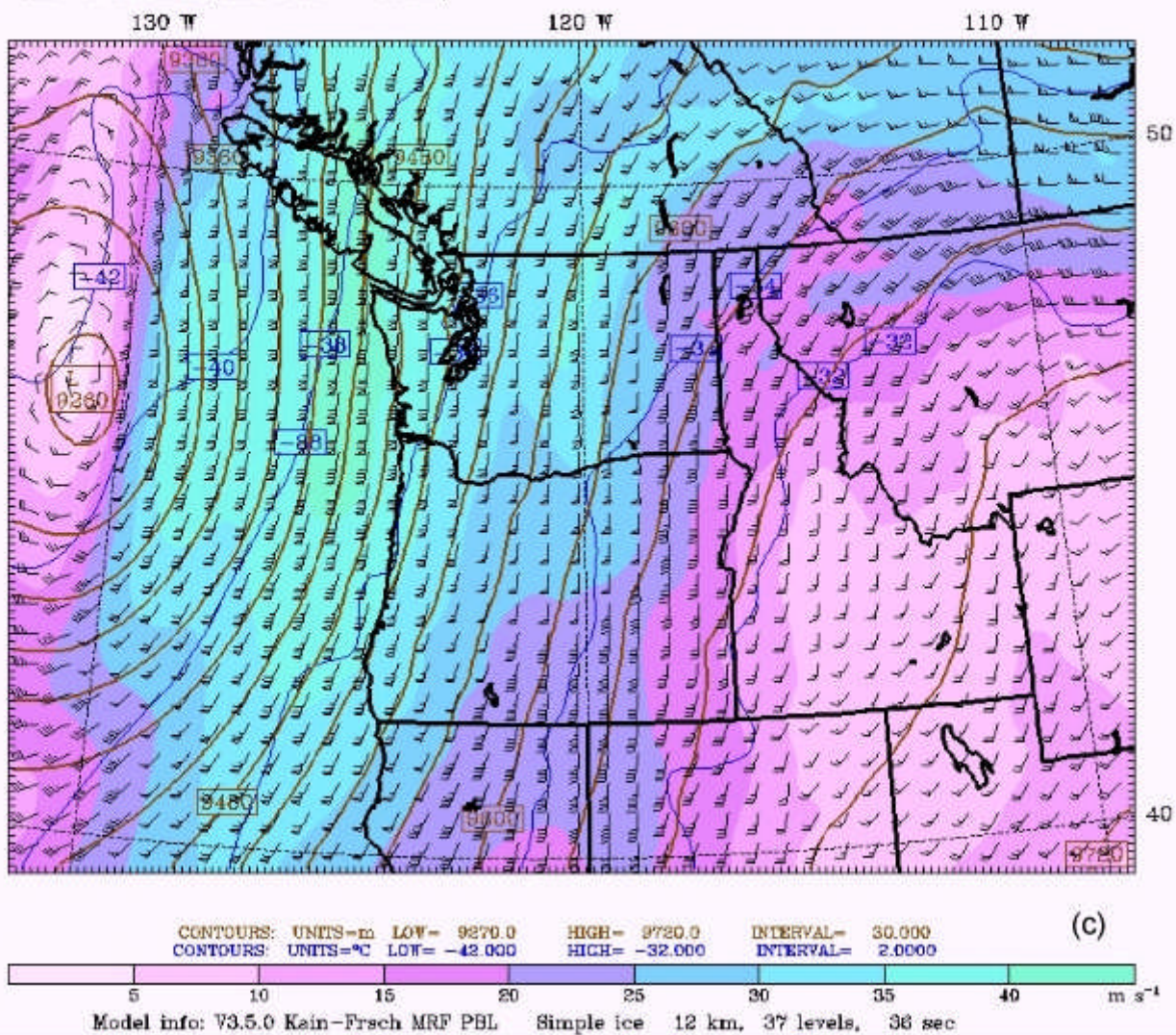


Figure 14c: MM5-ETA 300 mb wind speed ($\text{m}\cdot\text{s}^{-1}$), temperature ($^{\circ}\text{C}$), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 12 h

Absolute vorticity

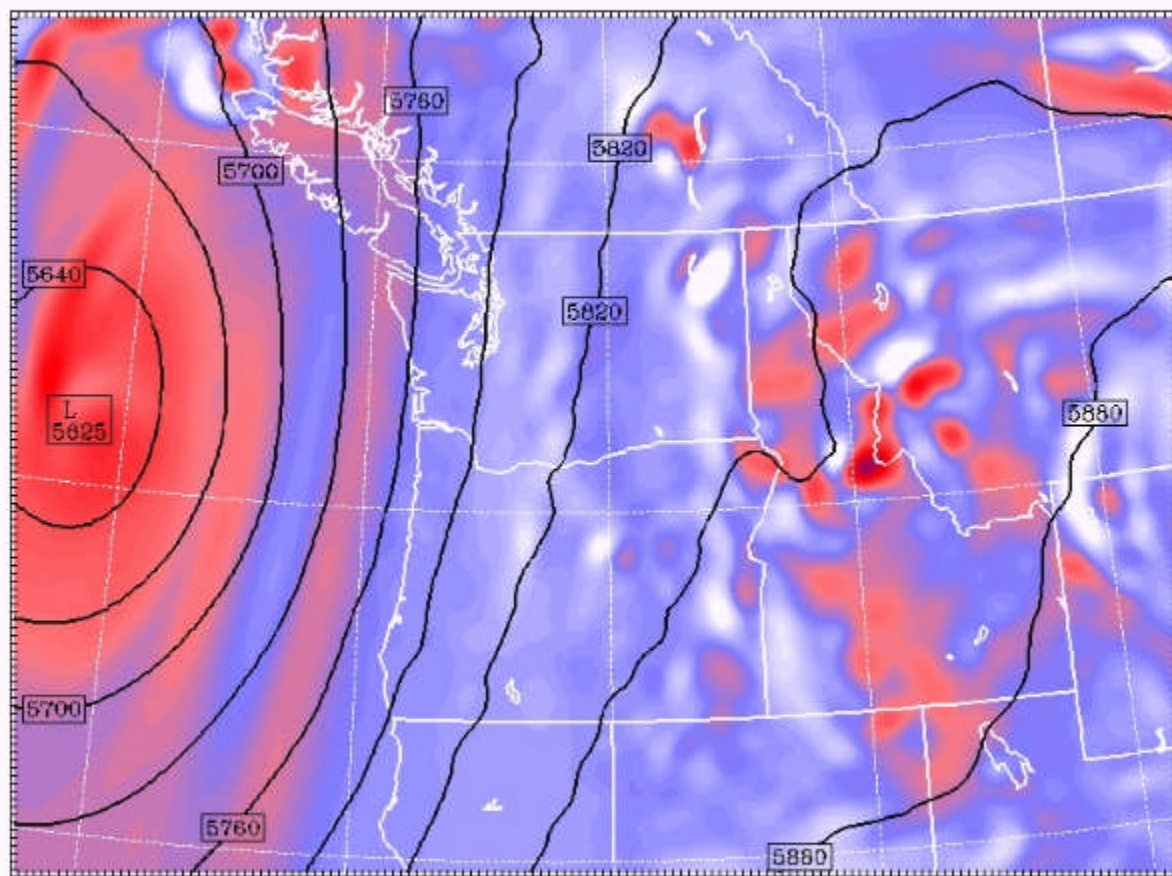
Geopotential Height at 500mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

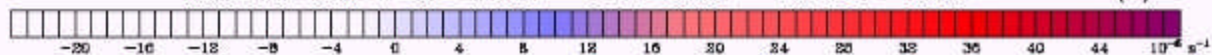
at pressure - 500 hPa

sm= 2



CONTOURS: UNITS=m LOW= 5640.0 HIGH= 5880.0 INTERVAL= 30.000

(d)



Model info: V3.5.0 Kain-Frsc MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 14d: MM5-ETA 500 mb absolute vorticity (s^{-1}) and geopotential height (m)

UW MM5-Eta 12km Domain

Fest: 12 h

Temperature at 700mb (°C)

Geopotential Height at 700mb (m)

Wind at 700mb (full barb = 10kts)

Init: 12 UTC Sun 18 Jul 04

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

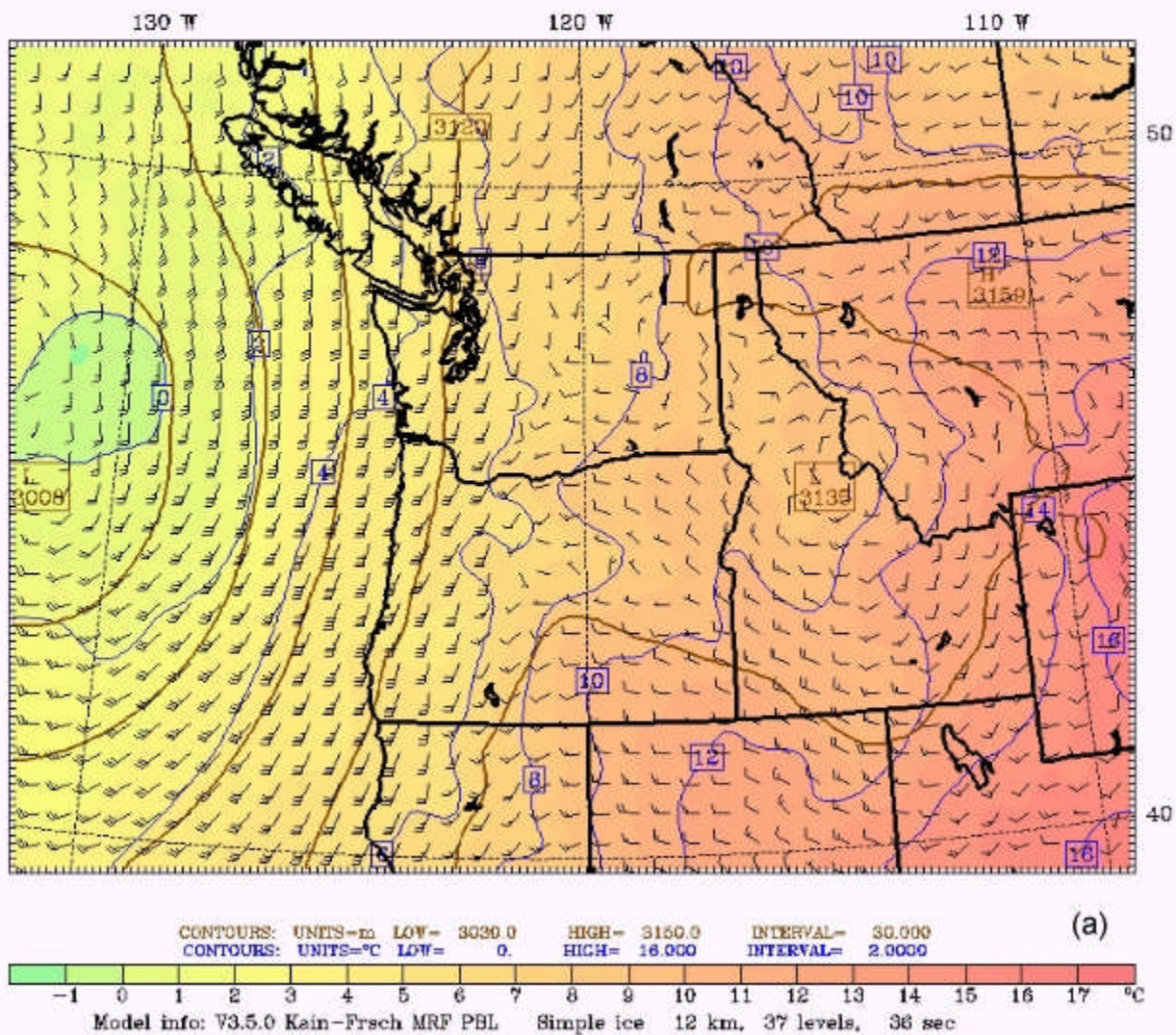


Figure 15a: MM5-ETA 700 mb temperature (°C), geopotential height (m), and wind (knots)

UW MM5-Eta 12km Domain

Fest: 12 h

Temperature at 850mb (°C)

Geopotential Height at 850mb (m)

Wind at 850mb (full barb = 10kts)

Init: 12 UTC Sun 18 Jul 04

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

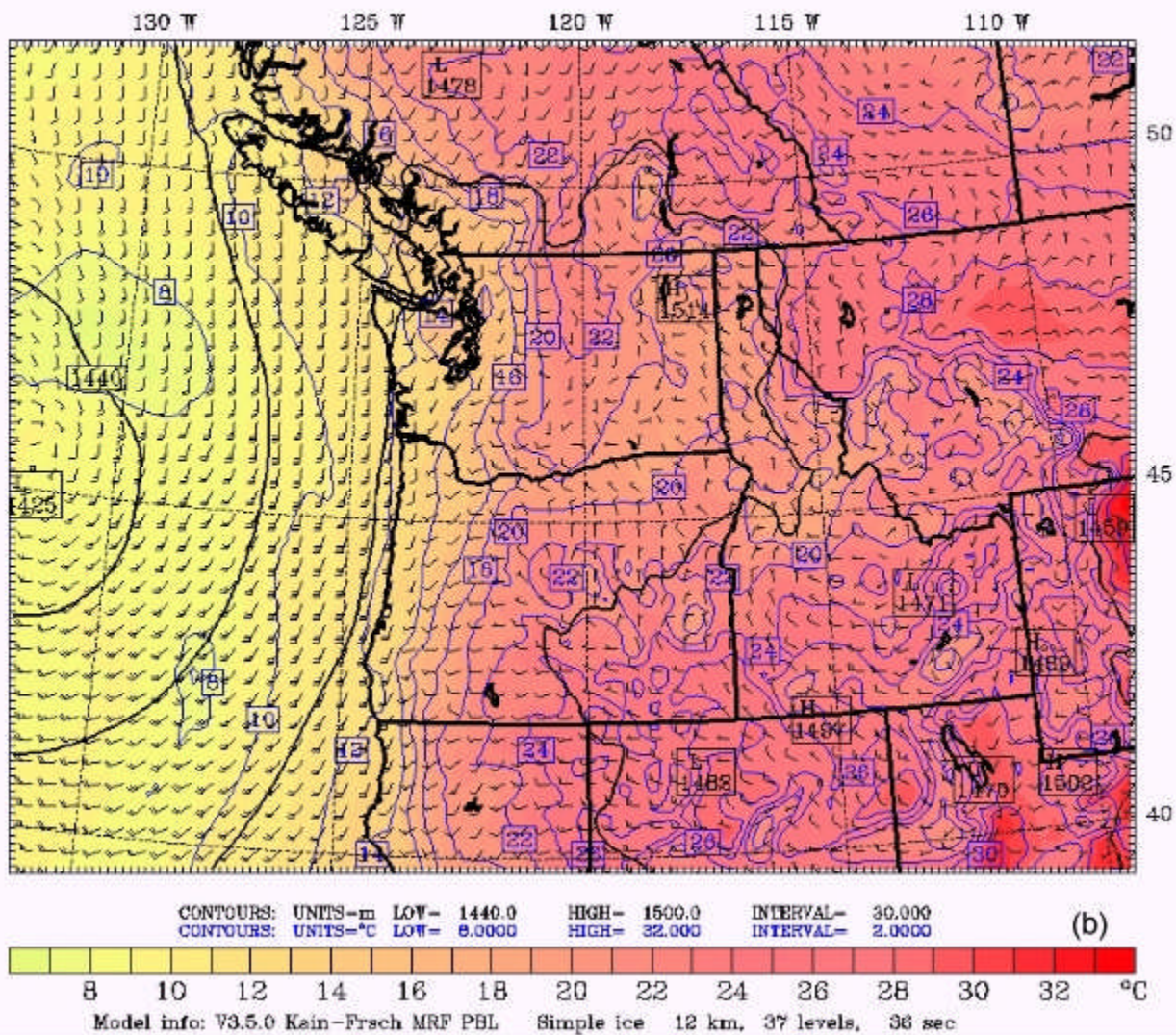


Figure 15b: MM5-ETA 850 mb temperature (°C), geopotential height (m), and wind (knots)

Init: 12 UTC Sun 18 Jul 04

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

Temperature at 925 mb (°C)

Sea Level Pressure (hPa)

Wind at 10m (full barb = 10kts)

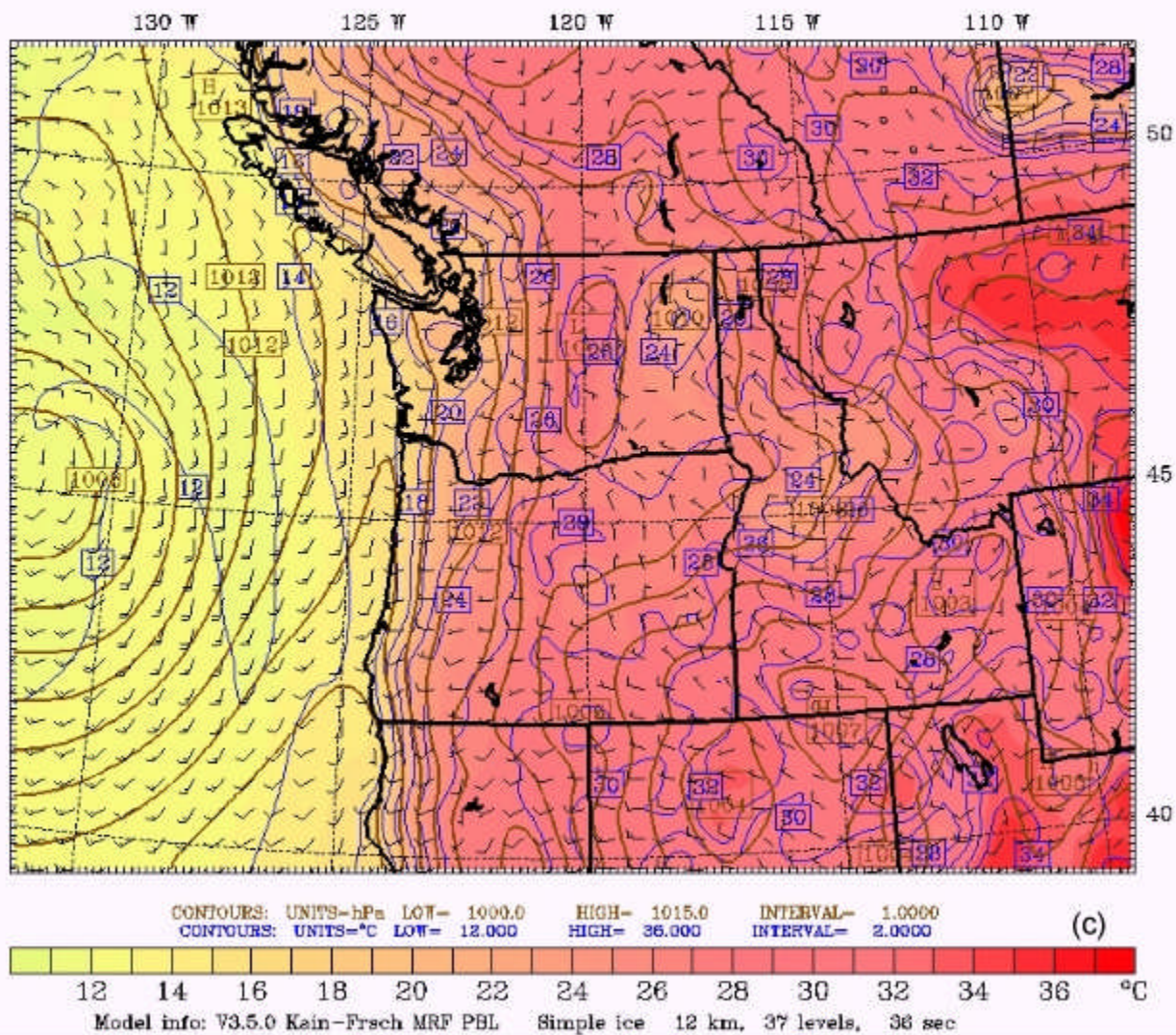


Figure 15c: MM5-ETA 925 mb temperature ($^{\circ}\text{C}$), mean sea-level pressure (hPa), and 10 m wind (knots)

UW MM5-Eta 12km Domain
 Fest: 12 h
 Maximum CAPE (J/kg)
 Sea Level Pressure (hPa)

Init: 12 UTC Sun 18 Jul 04
 Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

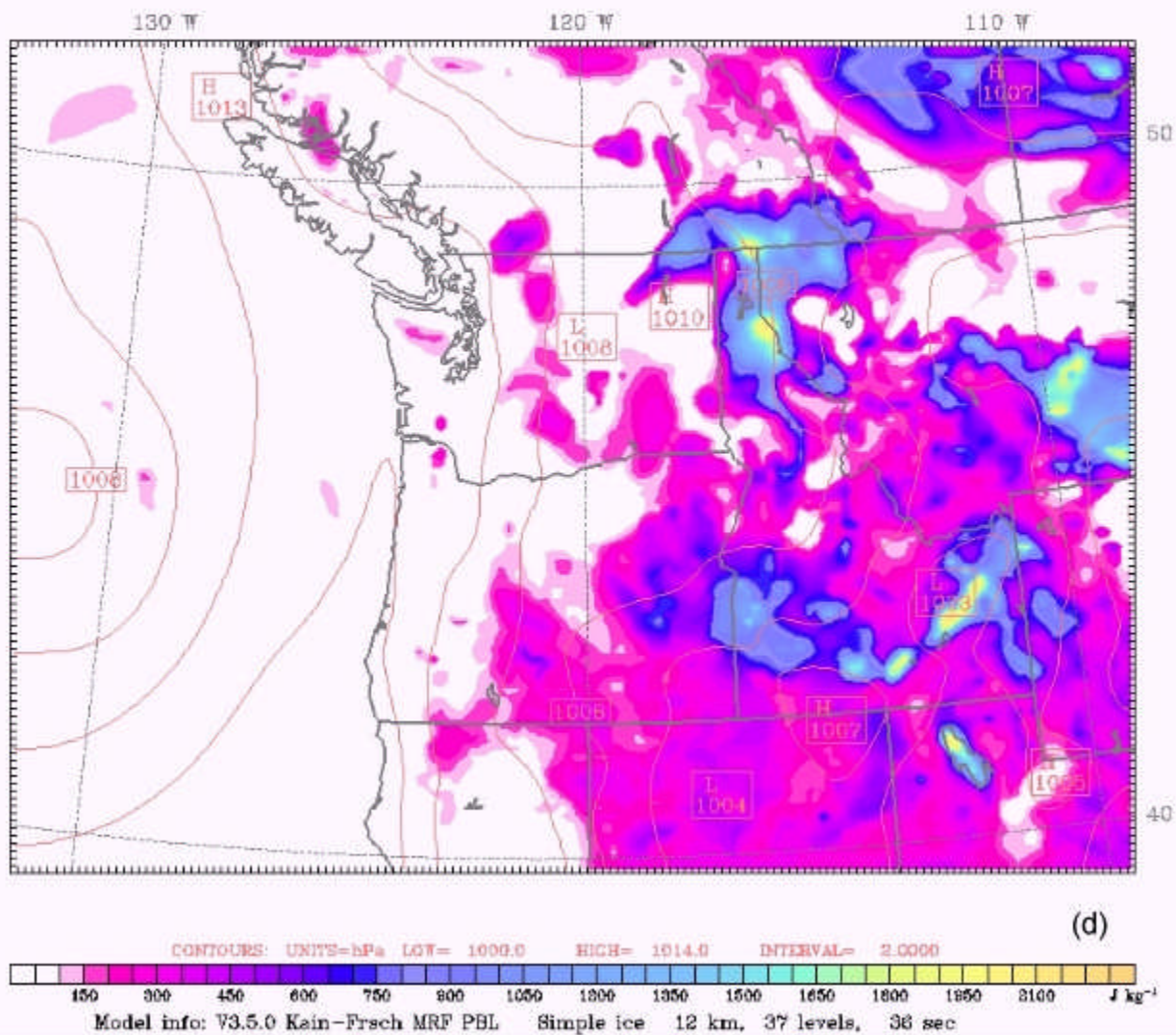


Figure 15d: MM5-ETA maximum CAPE (J kg^{-1}) and mean sea-level pressure (hPa)

UW MM5-Eta 12km Domain

Fest: 12 h

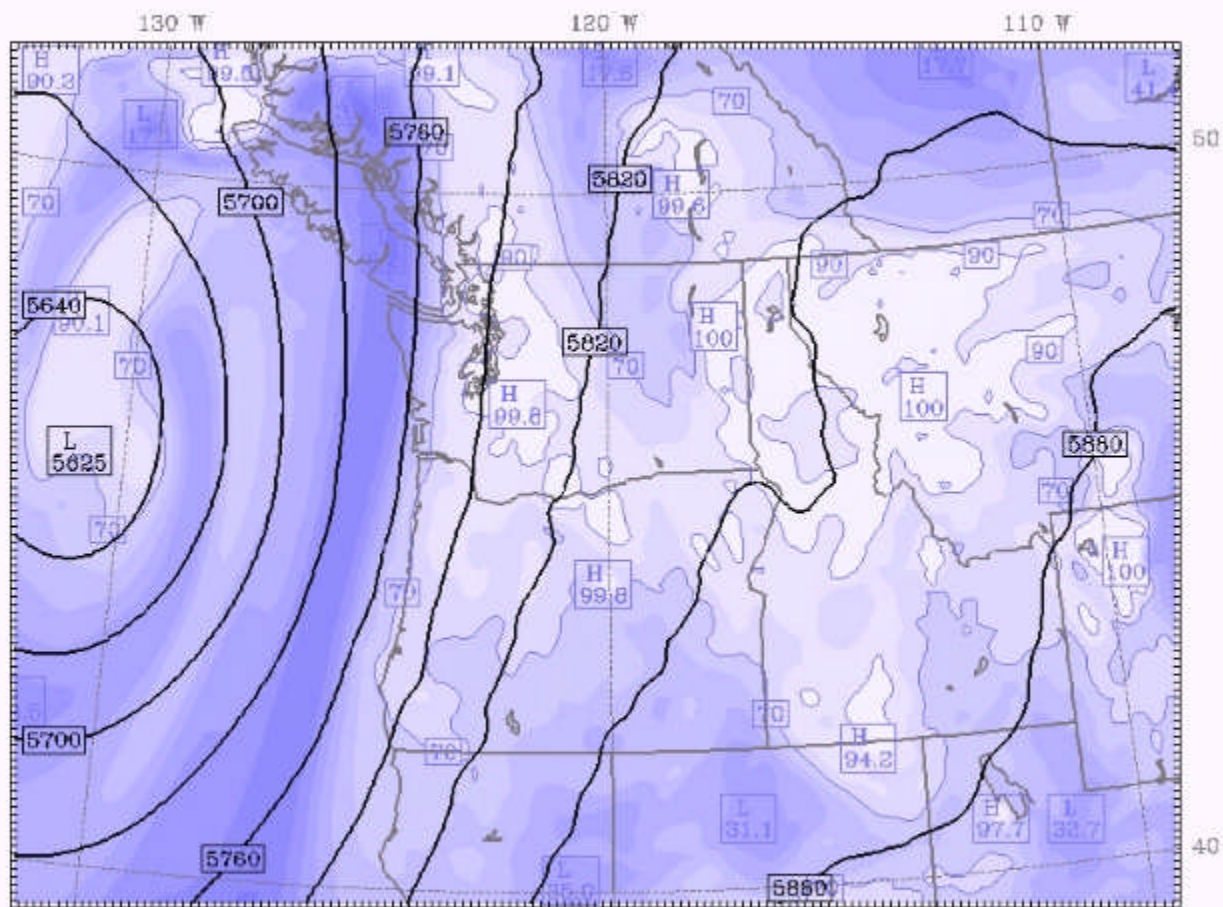
Relative humidity (w.r.t. water)

Geopotential Height at 500mb (m)

Init: 12 UTC Sun 18 Jul 04

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

at pressure - 500 hPa



CONTOURS: UNITS=m LOW= 5640.0 HIGH= 5880.0 INTERVAL= 30.000

(a)



Model info: V3.5.0 Kain-Franch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 16a: MM5-ETA 500 mb relative humidity (%) and geopotential height (m)

Init: 12 UTC Sun 18 Jul 04

Fest: 12 h

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

Relative humidity (w.r.t. water)

at pressure = 700 hPa

Geopotential Height at 700mb (m)

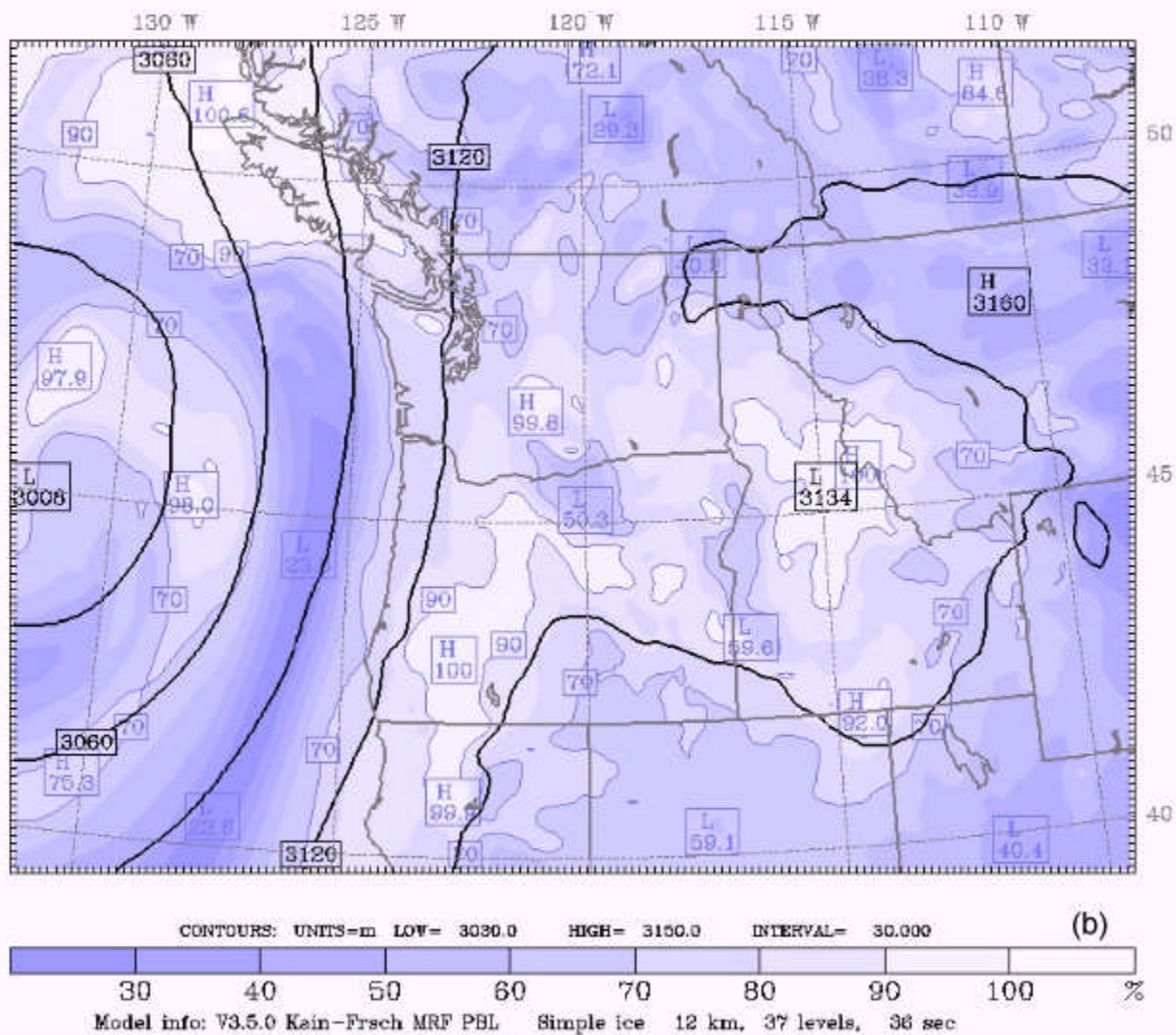


Figure 16b: MM5-ETA 700 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

Fest: 12 h

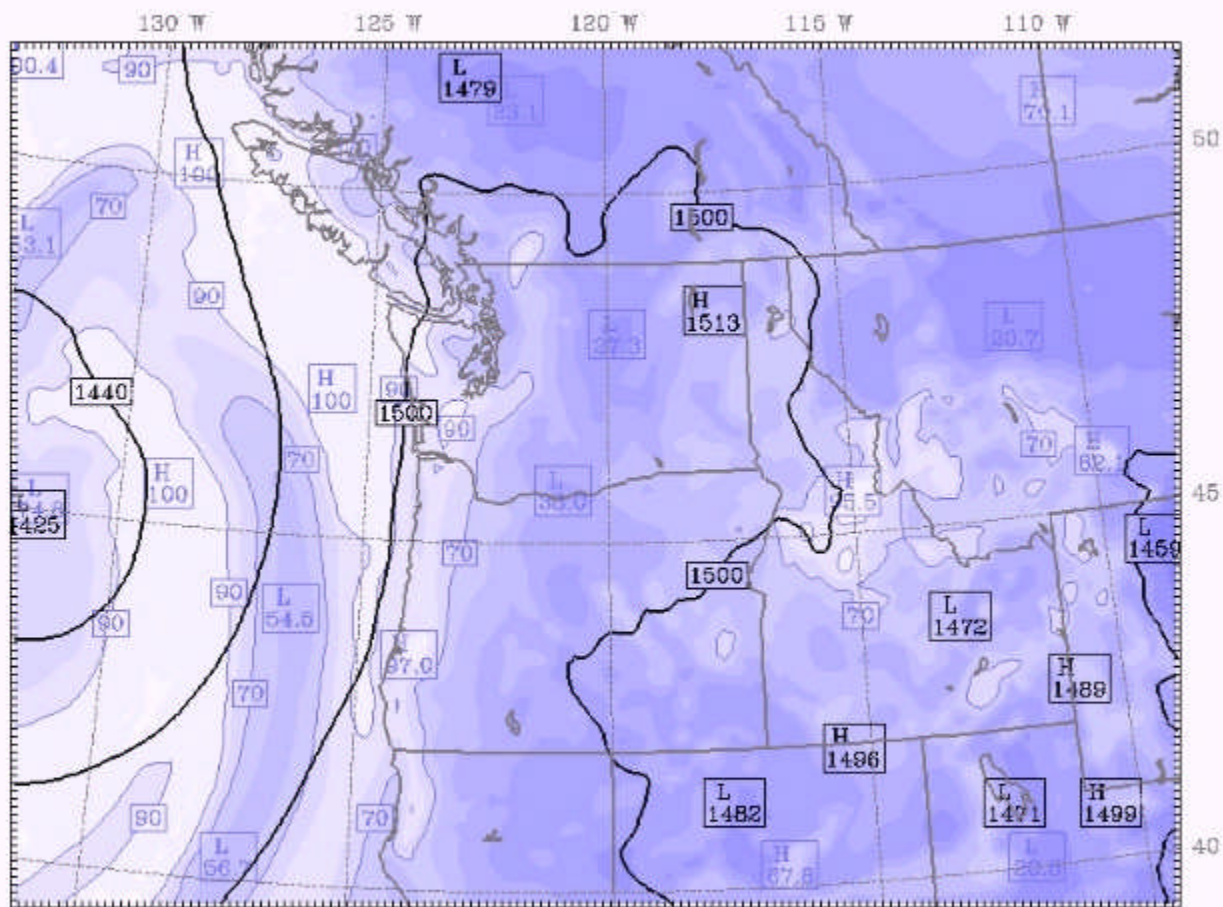
Relative humidity (w.r.t. water)

Geopotential Height at 850mb (m)

Init: 12 UTC Sun 18 Jul 04

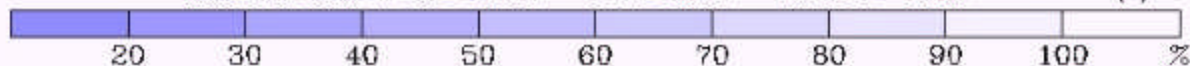
Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)

at pressure - 850 hPa



CONTOURS: UNITS=m LOW= 1440.0 HIGH= 1500.0 INTERVAL= 30.000

(c)



Model info: V3.5.0 Kain-Franch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 16c: MM5-ETA 850 mb relative humidity (%) and geopotential height (m)

UW MM5-Eta 12km Domain

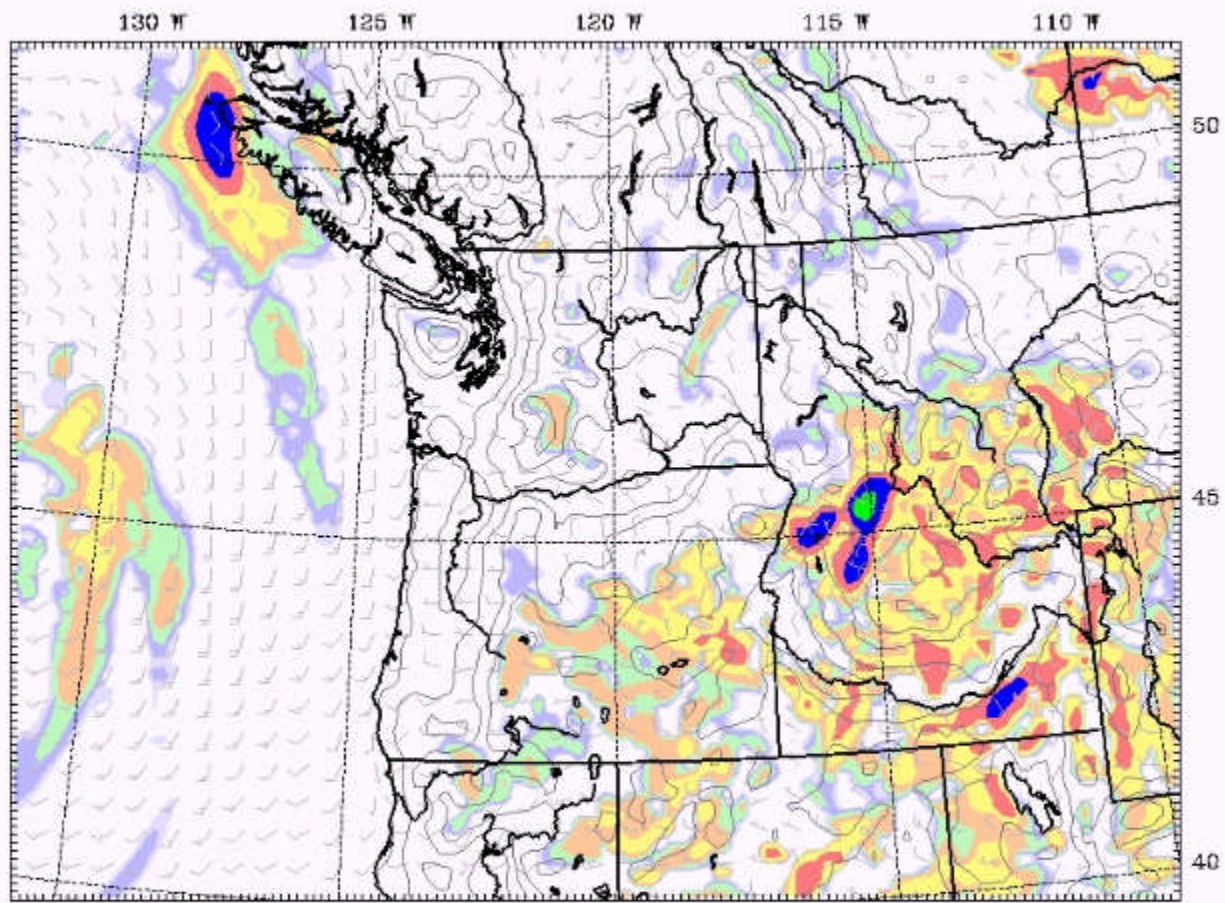
Fest: 12 h

Total Precip in past 3 hrs (.01in)

Wind at 10m (full barb = 10kts)

Init: 12 UTC Sun 18 Jul 04

Valid: 00 UTC Mon 19 Jul 04 (17 PDT Sun 18 Jul 04)



(d)

1/100 inch



Model info: V3.5.0 Kain-Frösch MRF PBL Simple ice 12 km, 37 levels, 36 sec

Figure 16d: MM5-ETA total precipitation in past 3 hours (inches) and 10 m wind (knots)

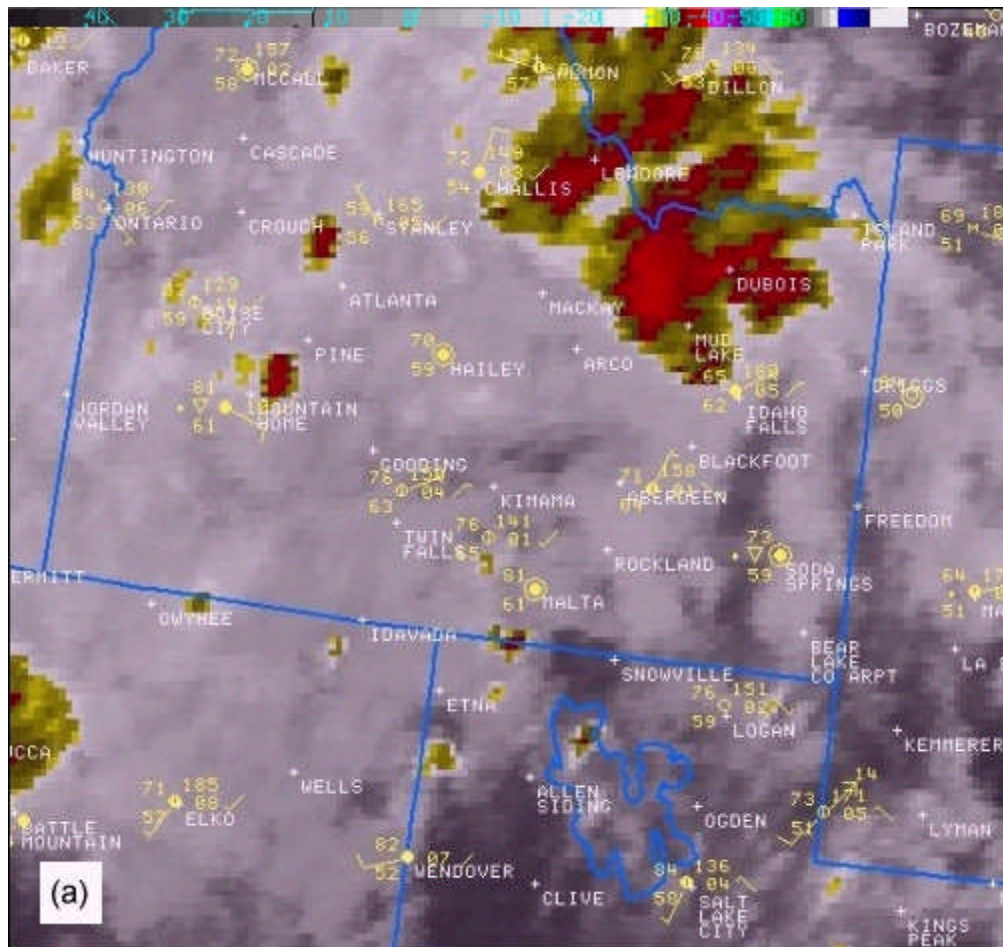


Figure 17a: NOAA GOES 4 km Infrared Satellite : 1800 UTC 18 July 2004
 NOAA NWS METAR Observations : 1800 UTC 18 July 2004

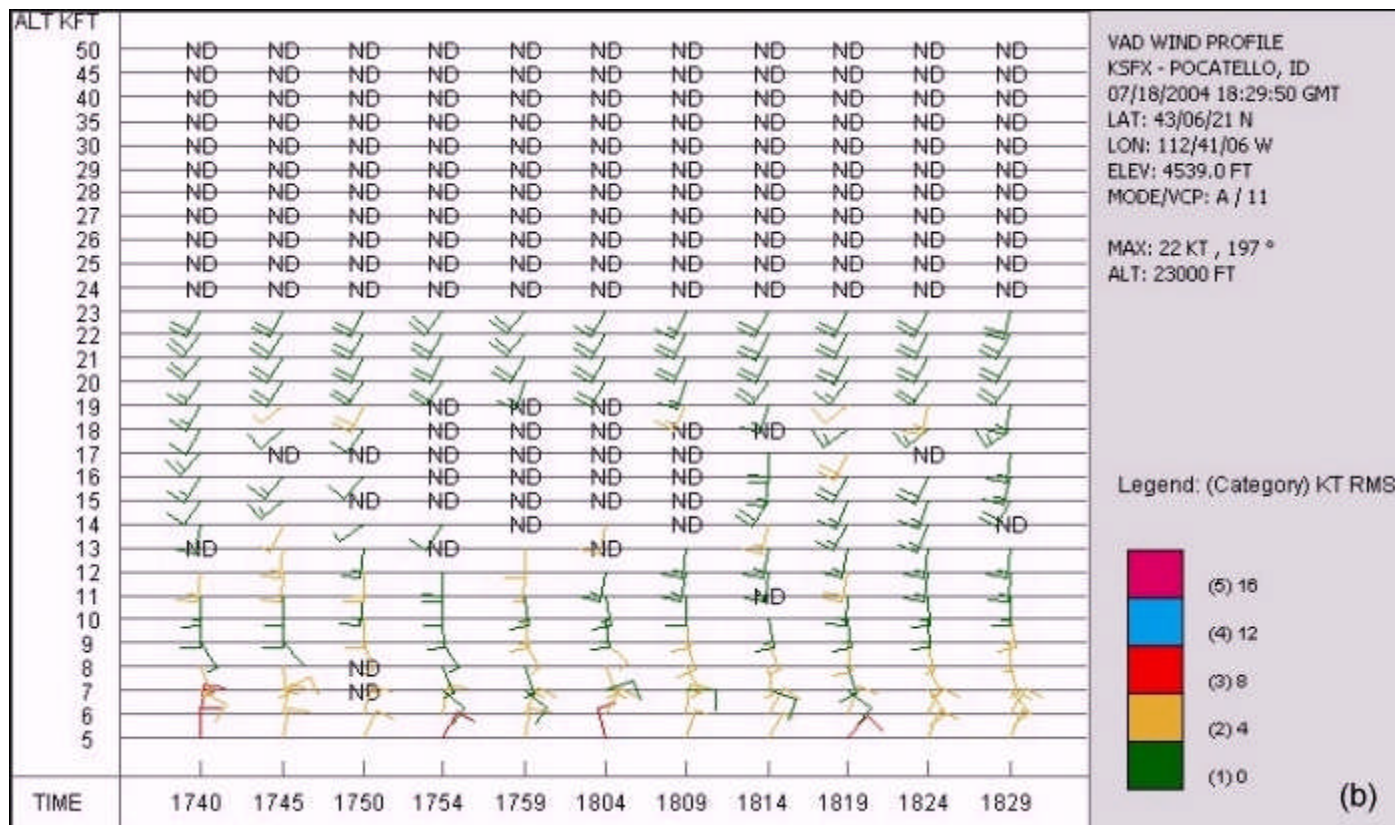


Figure 17b: KSPX WSR-88D VAD Wind Profile (knots) : [1740 UTC to 1829 UTC] 18 July 2004

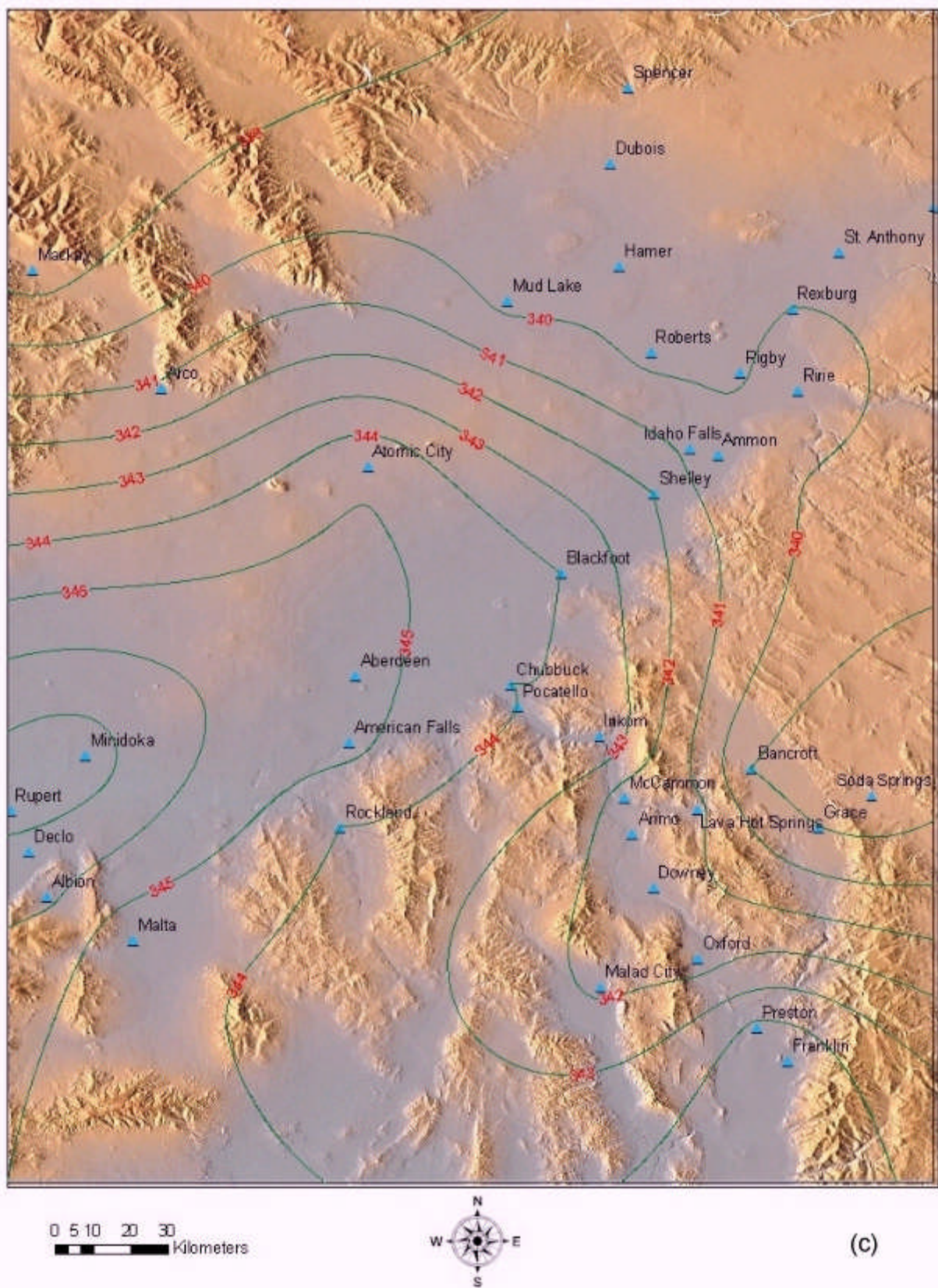


Figure 17c: MSAS Surface Equivalent Potential Temperature ($^{\circ}\text{K}$) : 1800 UTC 18 July 2004

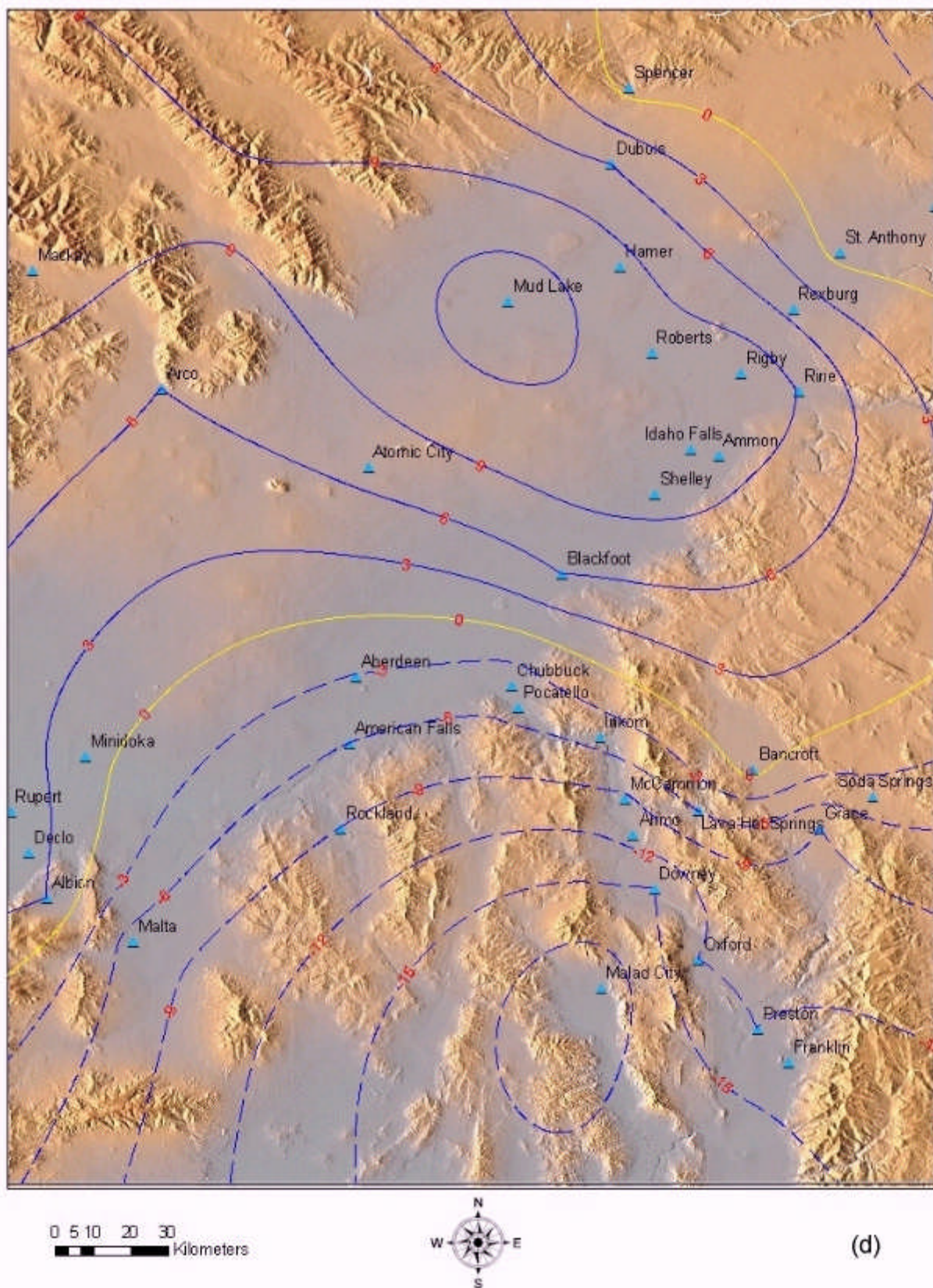


Figure 17d: MSAS Surface Moisture Flux Divergence ($\text{g} \cdot 12 \text{ hr} \cdot \text{kg}^{-1}$) : 1800 UTC 18 July 2004

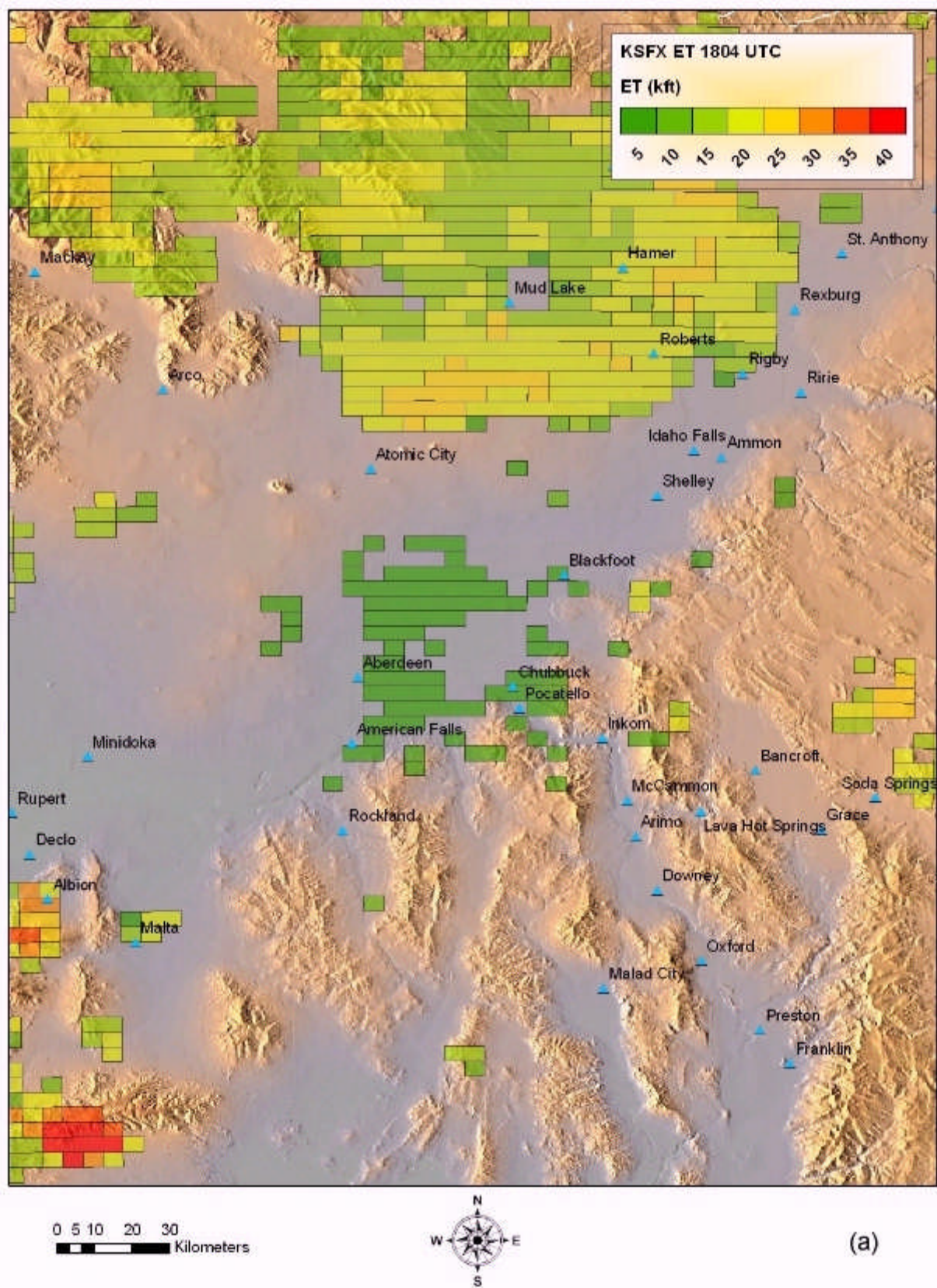


Figure 18a: KSFX WSR-88D Echo Tops (kft) : 1804 UTC 18 July 2004

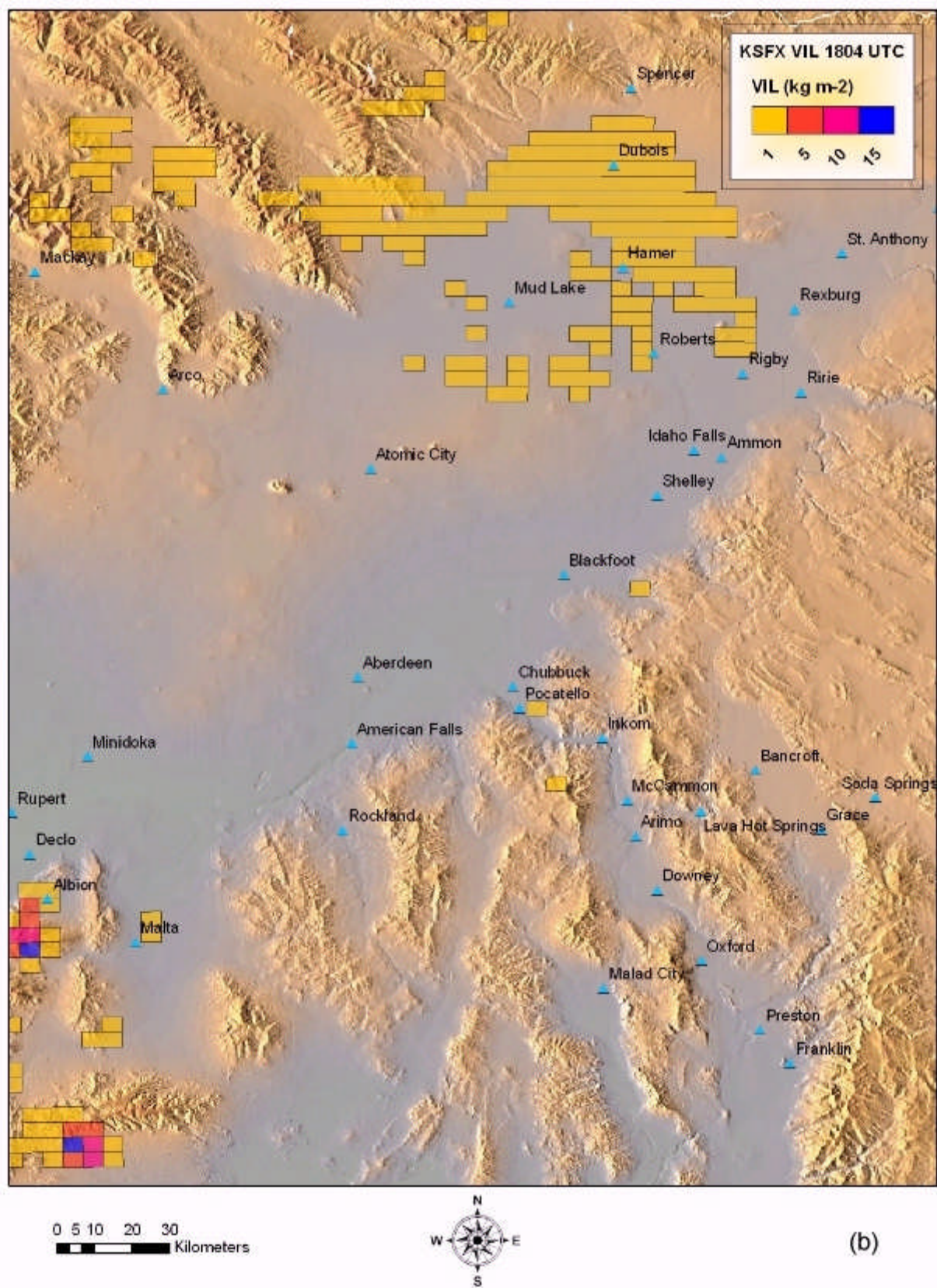


Figure 18b: KSFX WSR-88D Vertically Integrated Liquid (kg m^{-2}) : 1804 UTC 18 July 2004

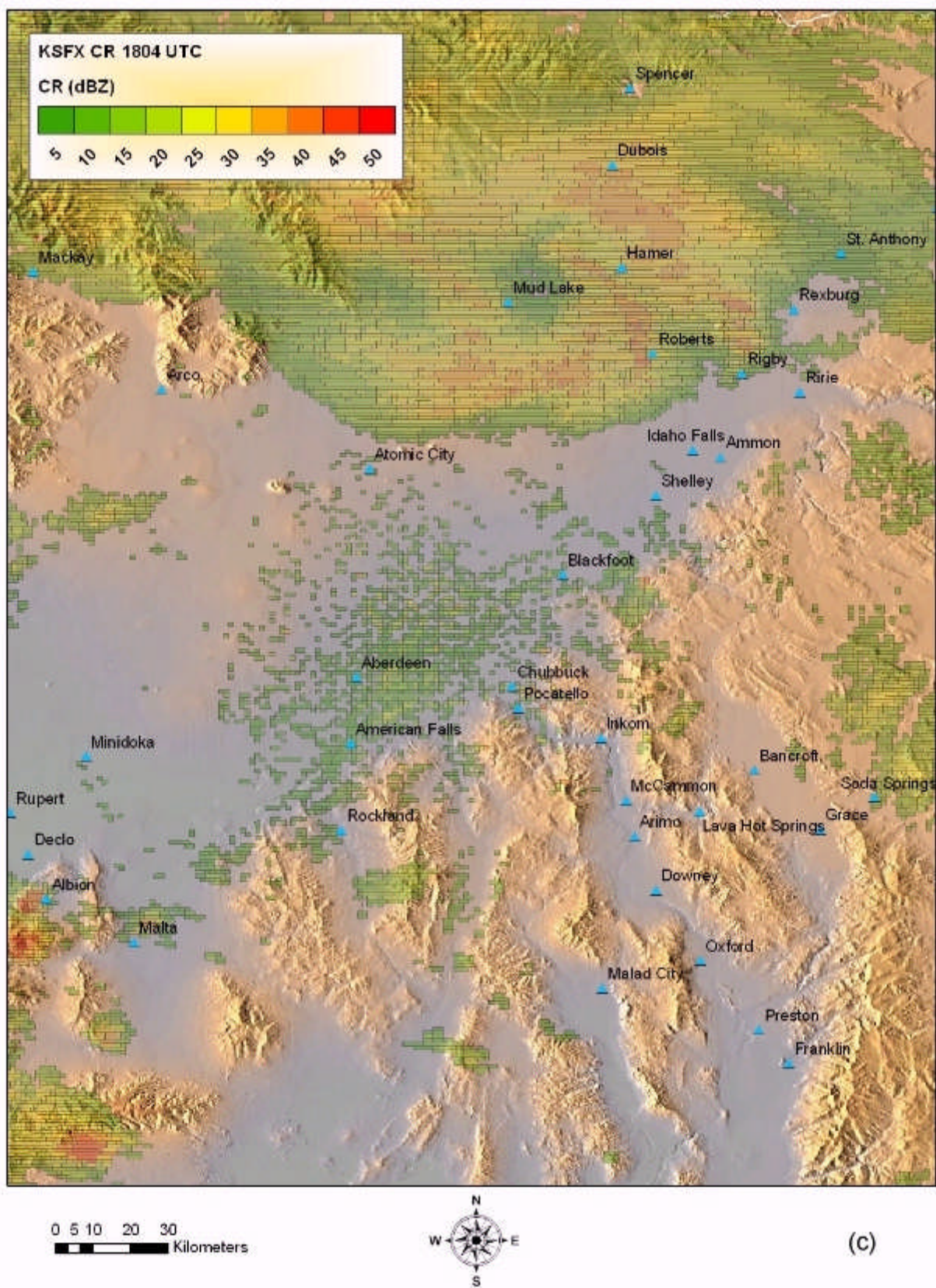


Figure 18c: KSFY WSR-88D Composite Reflectivity (dBZ) : 1804 UTC 18 July 2004

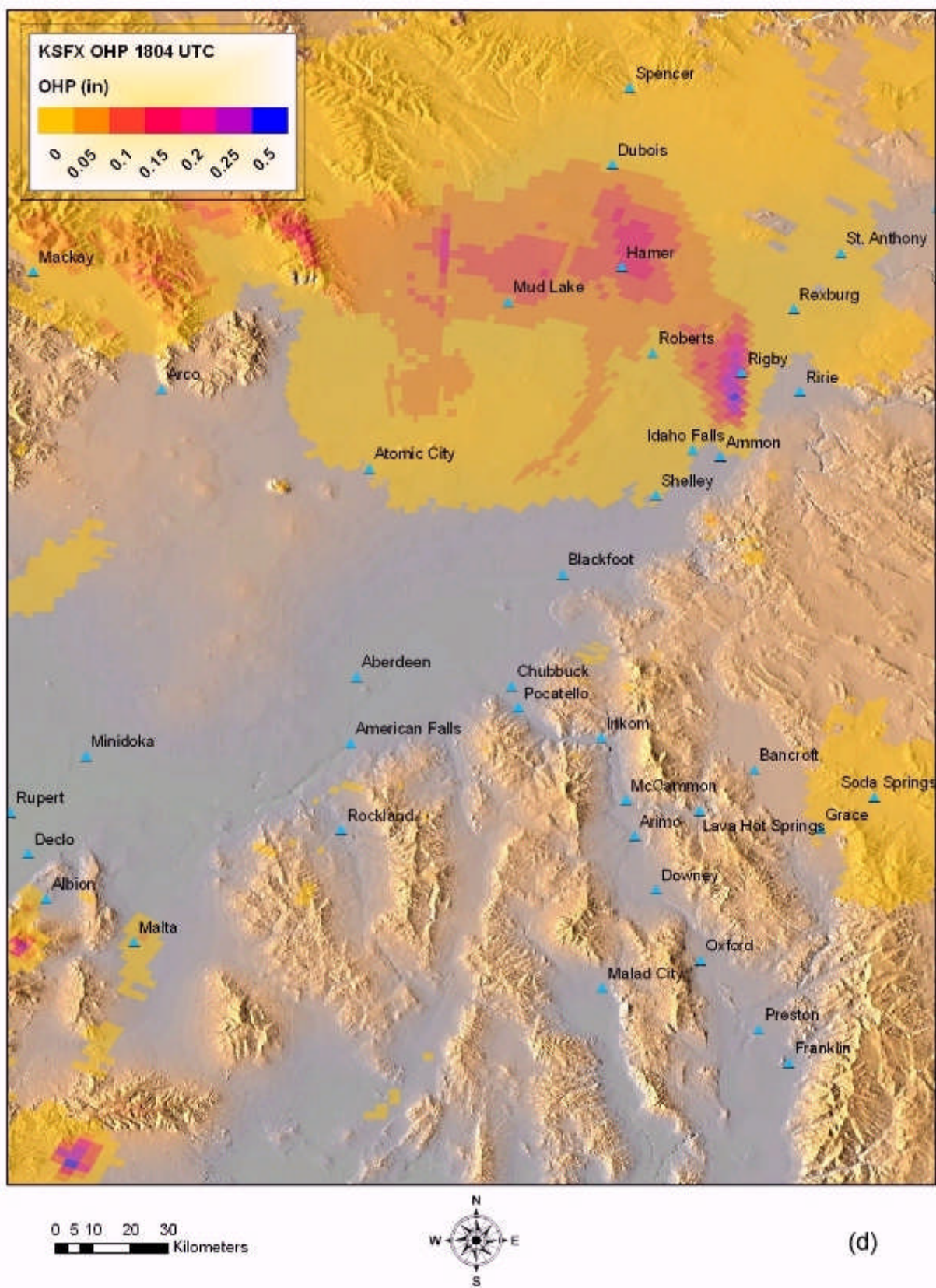


Figure 18d: KSFx WSR-88D One Hour Precipitation (inches) : 1804 UTC 18 July 2004

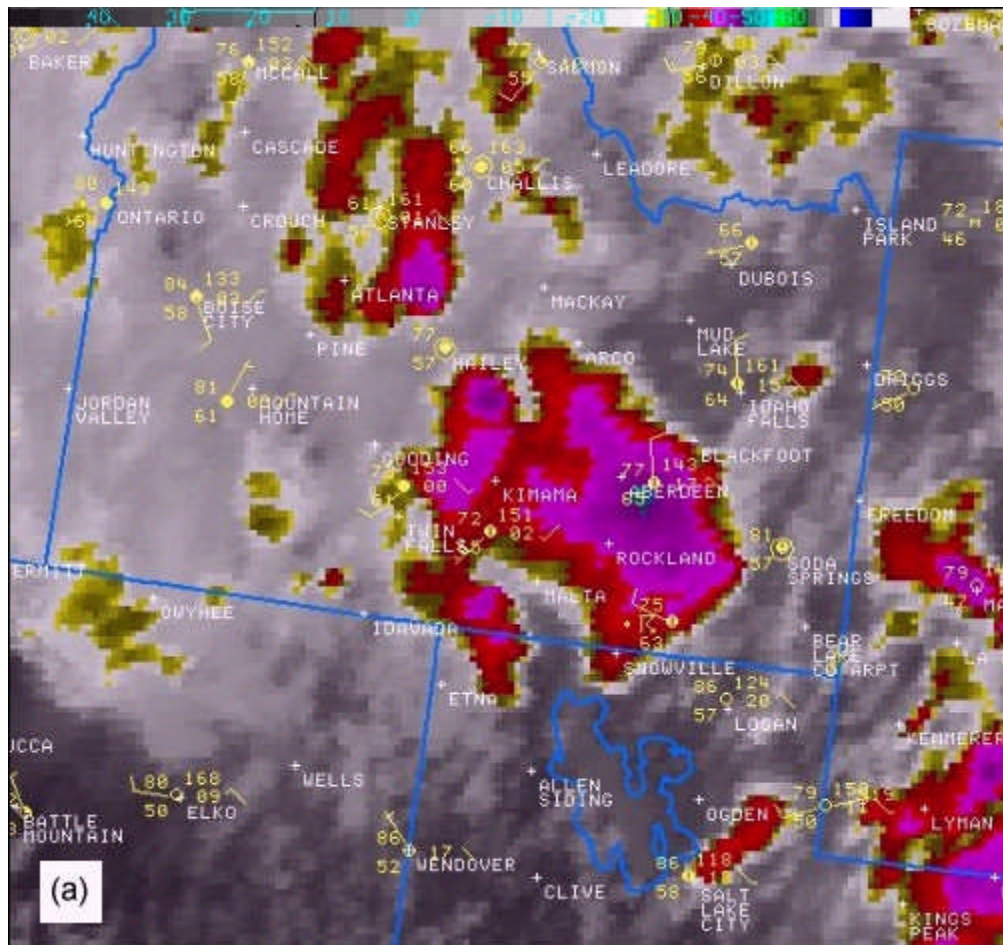


Figure 19a: NOAA GOES 4 km Infrared Satellite : 2100 UTC 18 July 2004
 NOAA NWS METAR Observations : 2100 UTC 18 July 2004

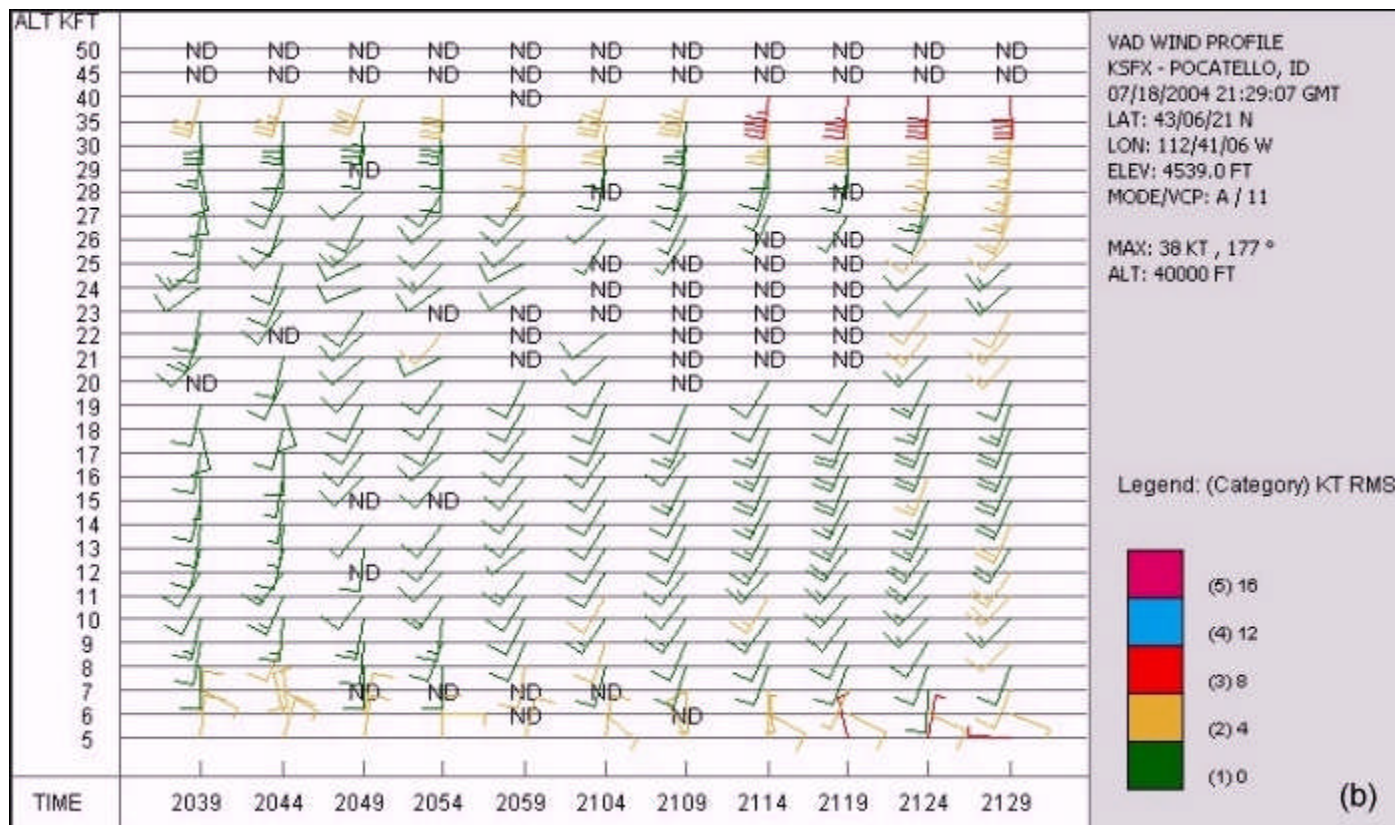


Figure 19b: KSPX WSR-88D VAD Wind Profile (knots) : [2039 UTC to 2129 UTC] 18 July 2004

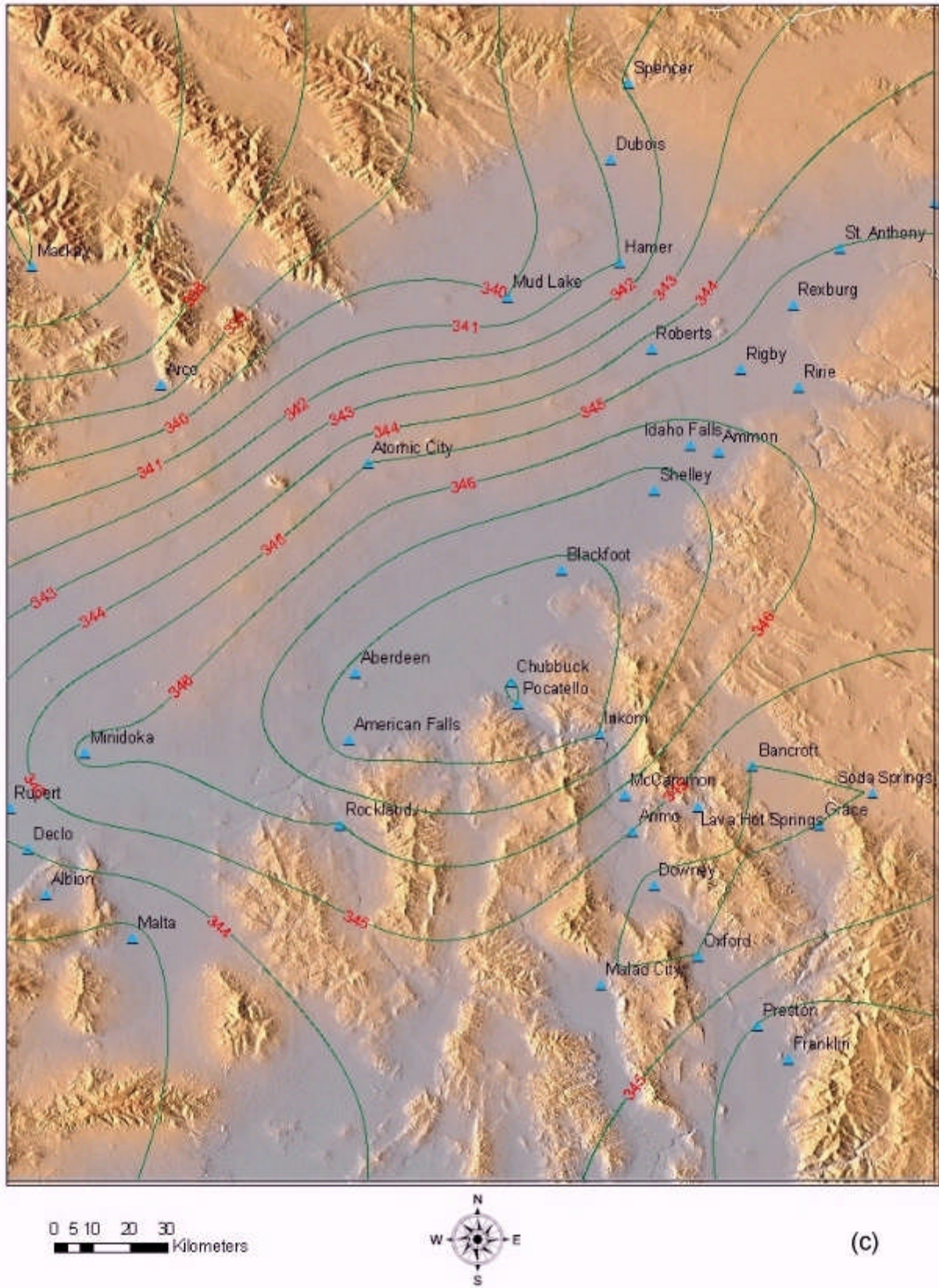


Figure 19c: MSAS Surface Equivalent Potential Temperature ($^{\circ}\text{K}$) : 2100 UTC 18 July 2004

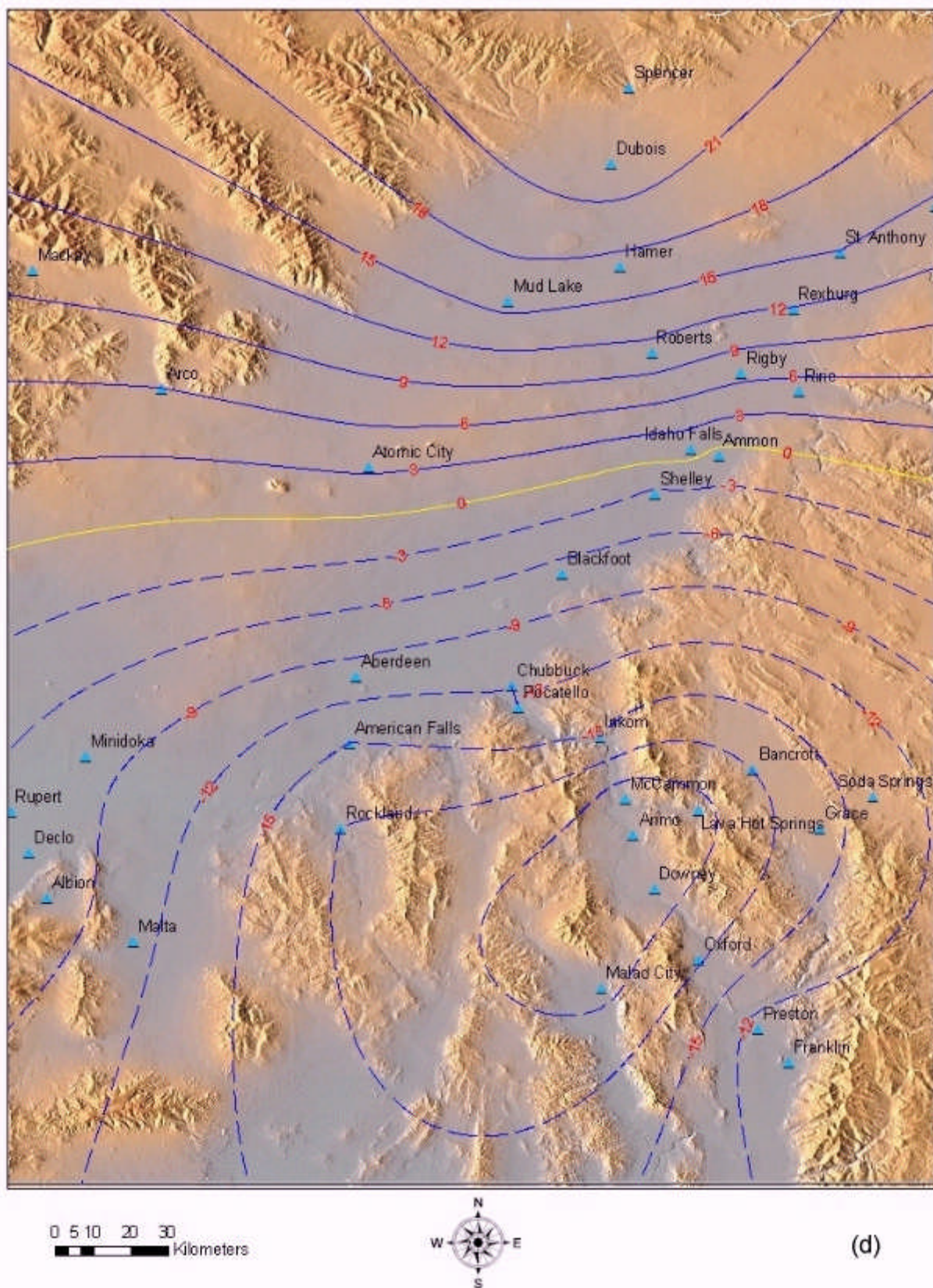


Figure 19d: MSAS Surface Moisture Flux Divergence (g·12 hr·kg⁻¹) : 2100 UTC 18 July 2004

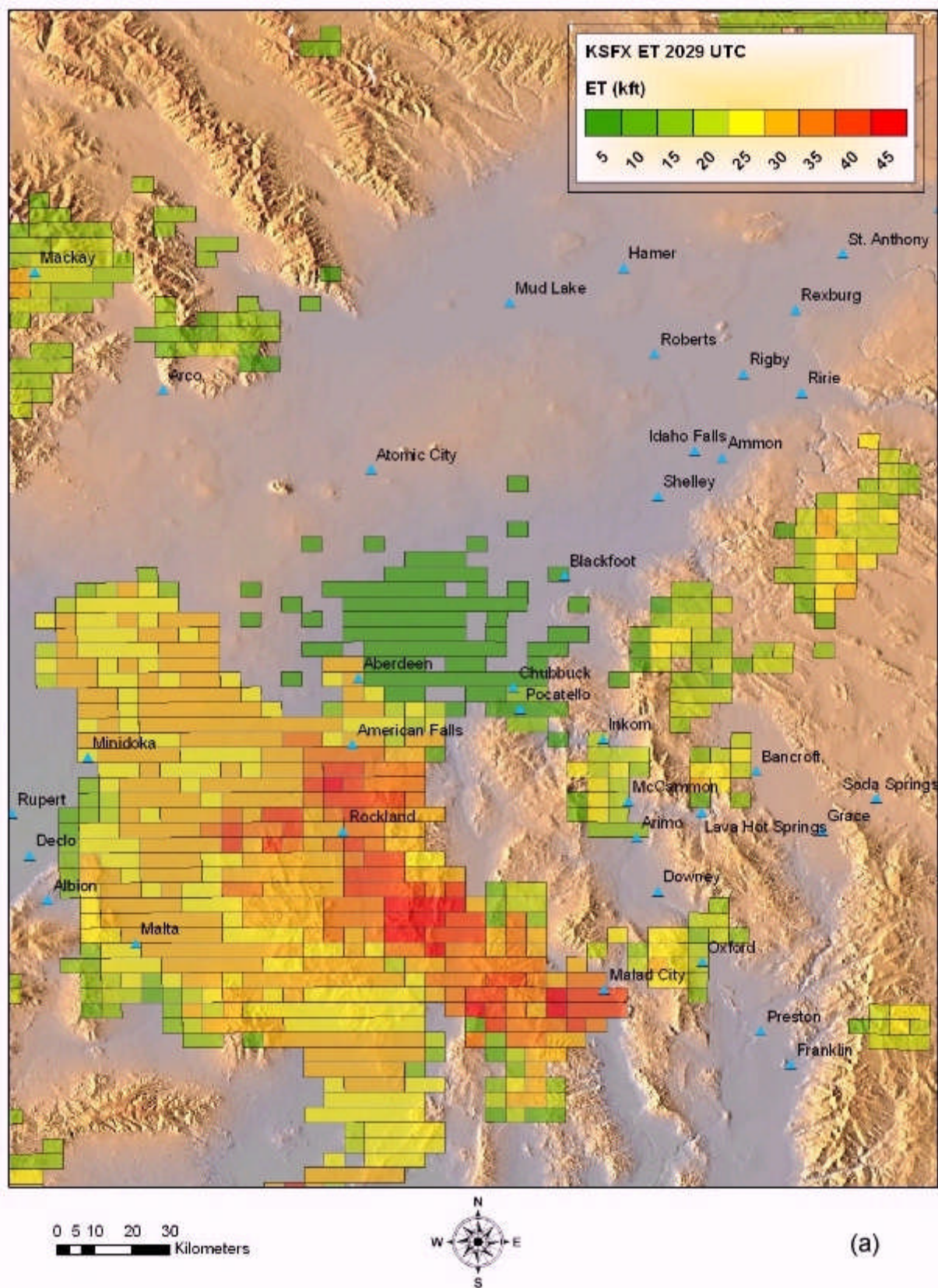


Figure 20a: KSFx WSR-88D Echo Tops (kft) : 2029 UTC 18 July 2004

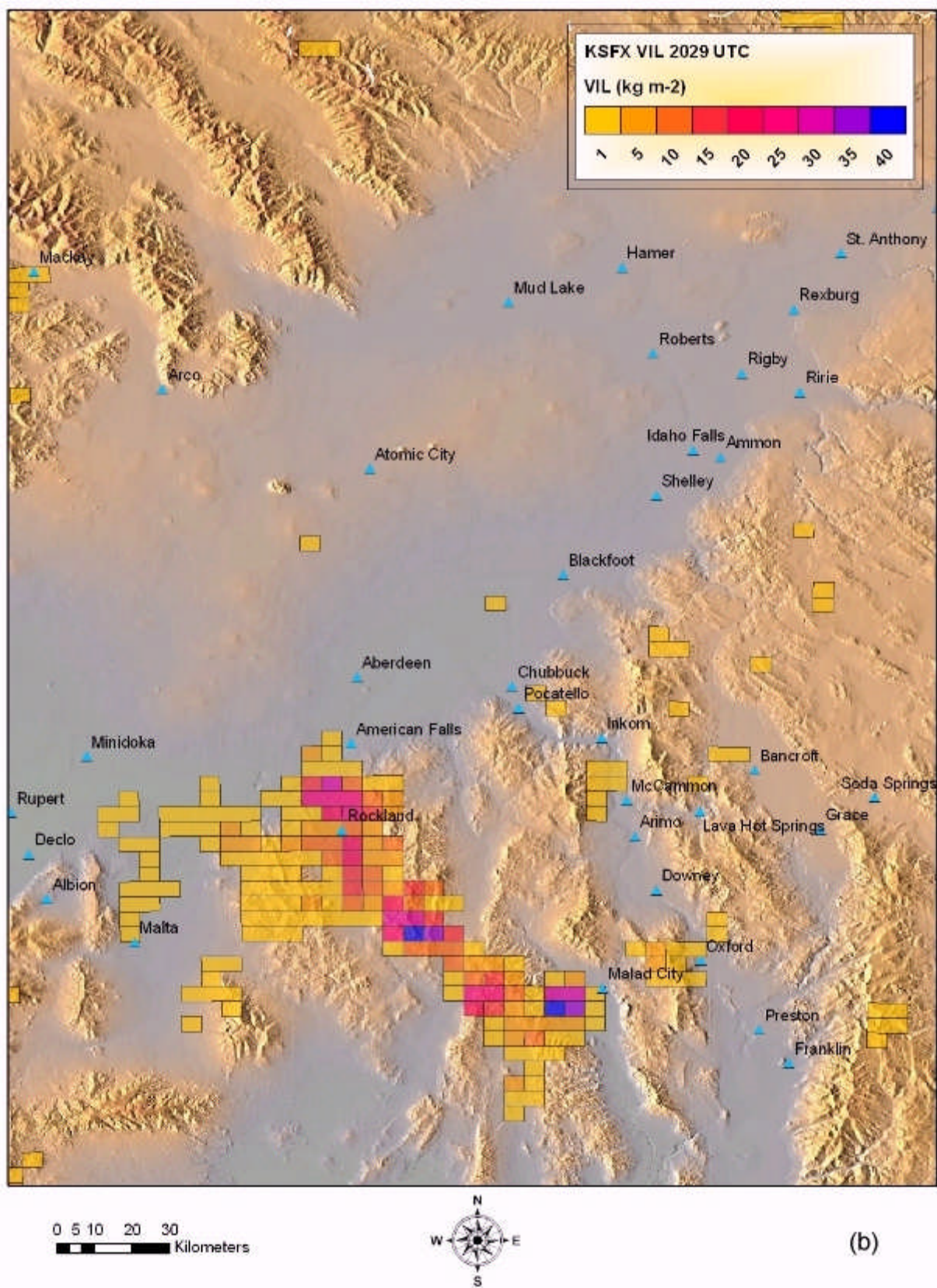


Figure 20b: KSFx WSR-88D Vertically Integrated Liquid (kg m^{-2}) : 2029 UTC 18 July 2004

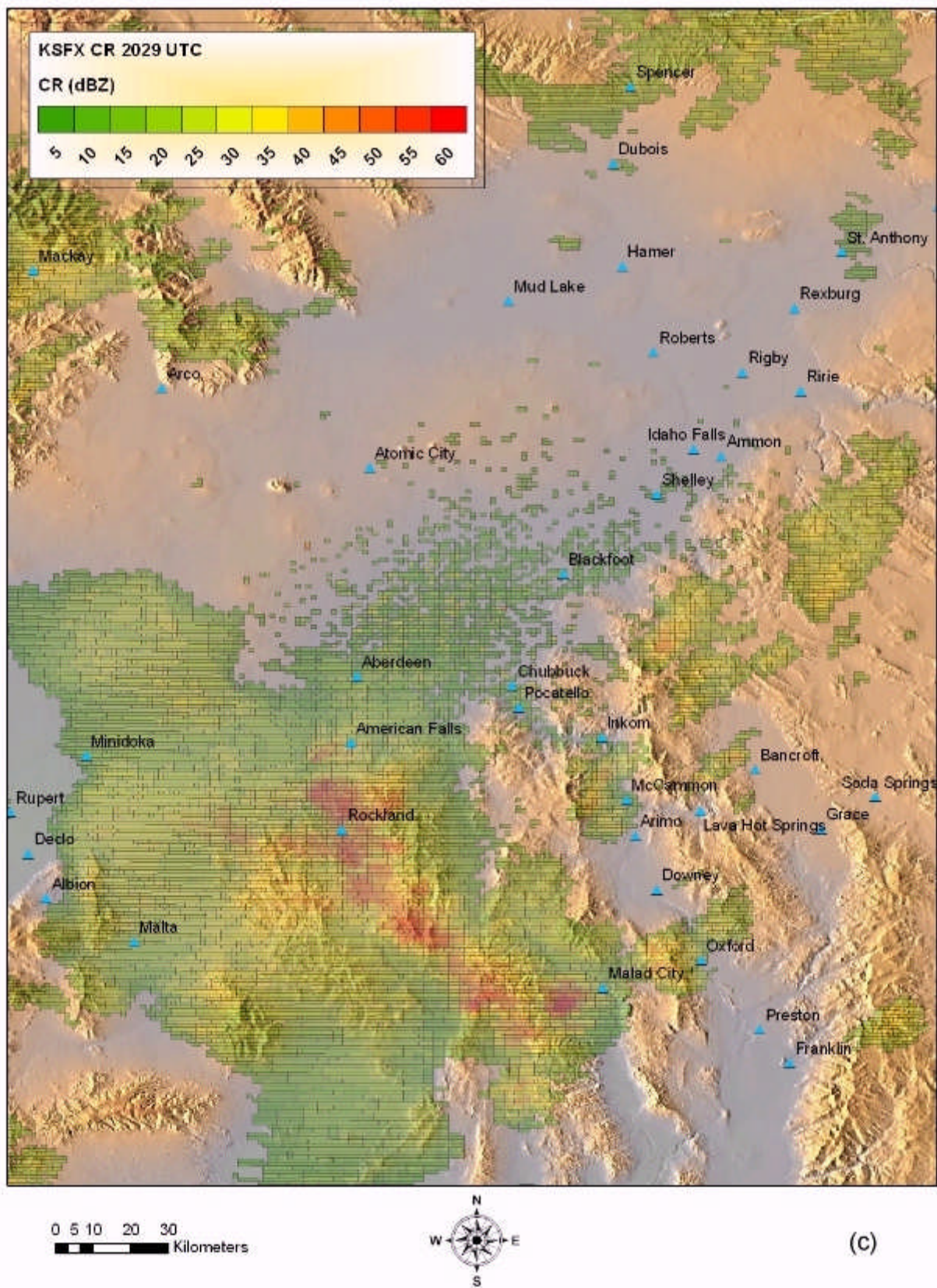


Figure 20c: KSFX WSR-88D Composite Reflectivity (dBZ) : 2029 UTC 18 July 2004

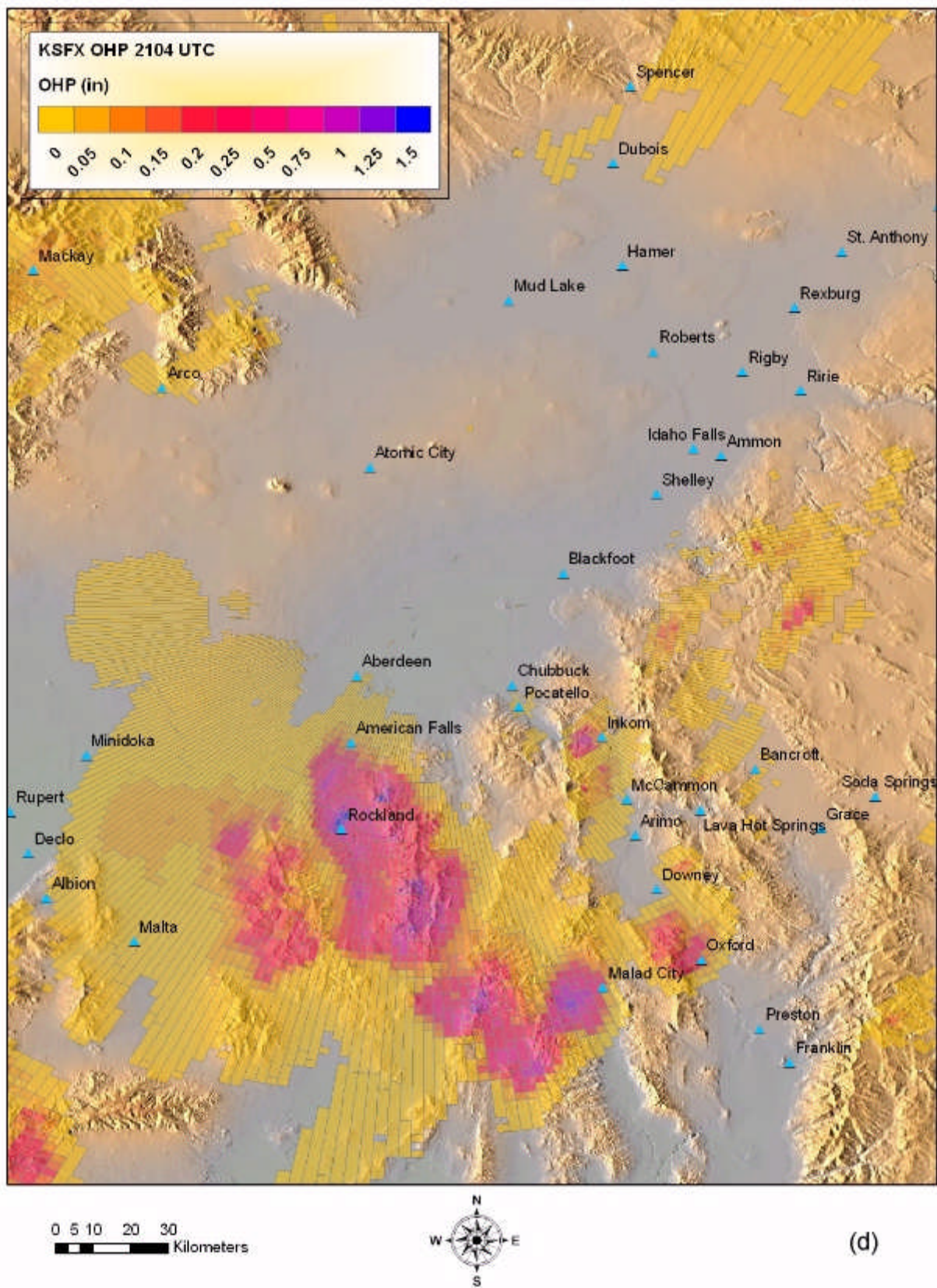


Figure 20d: KSFX WSR-88D One Hour Precipitation (inches) : 2104 UTC 18 July 2004

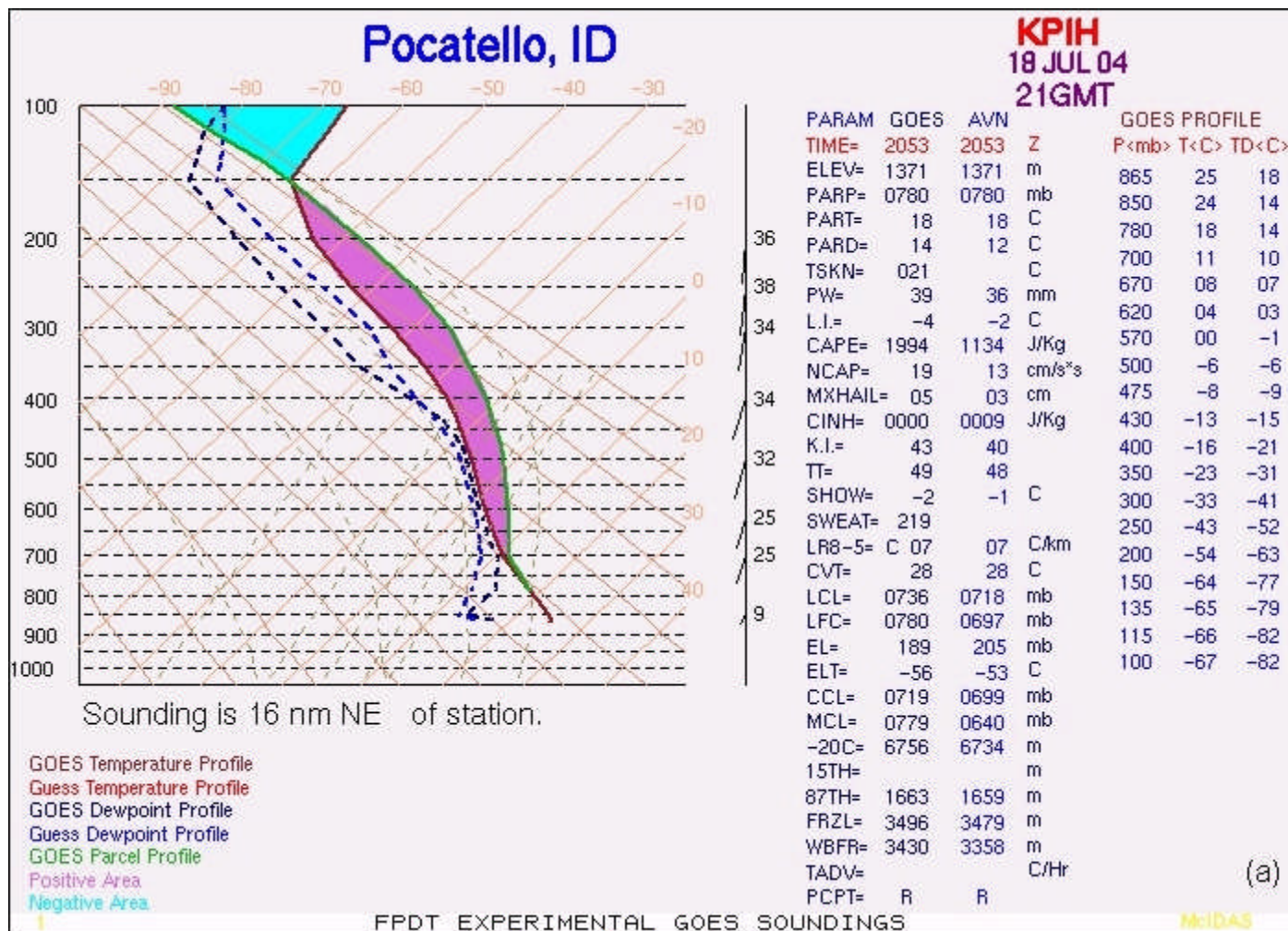


Figure 21a: NOAA GOES Sounding for Pocatello, Idaho : 2100 UTC 18 July 2004

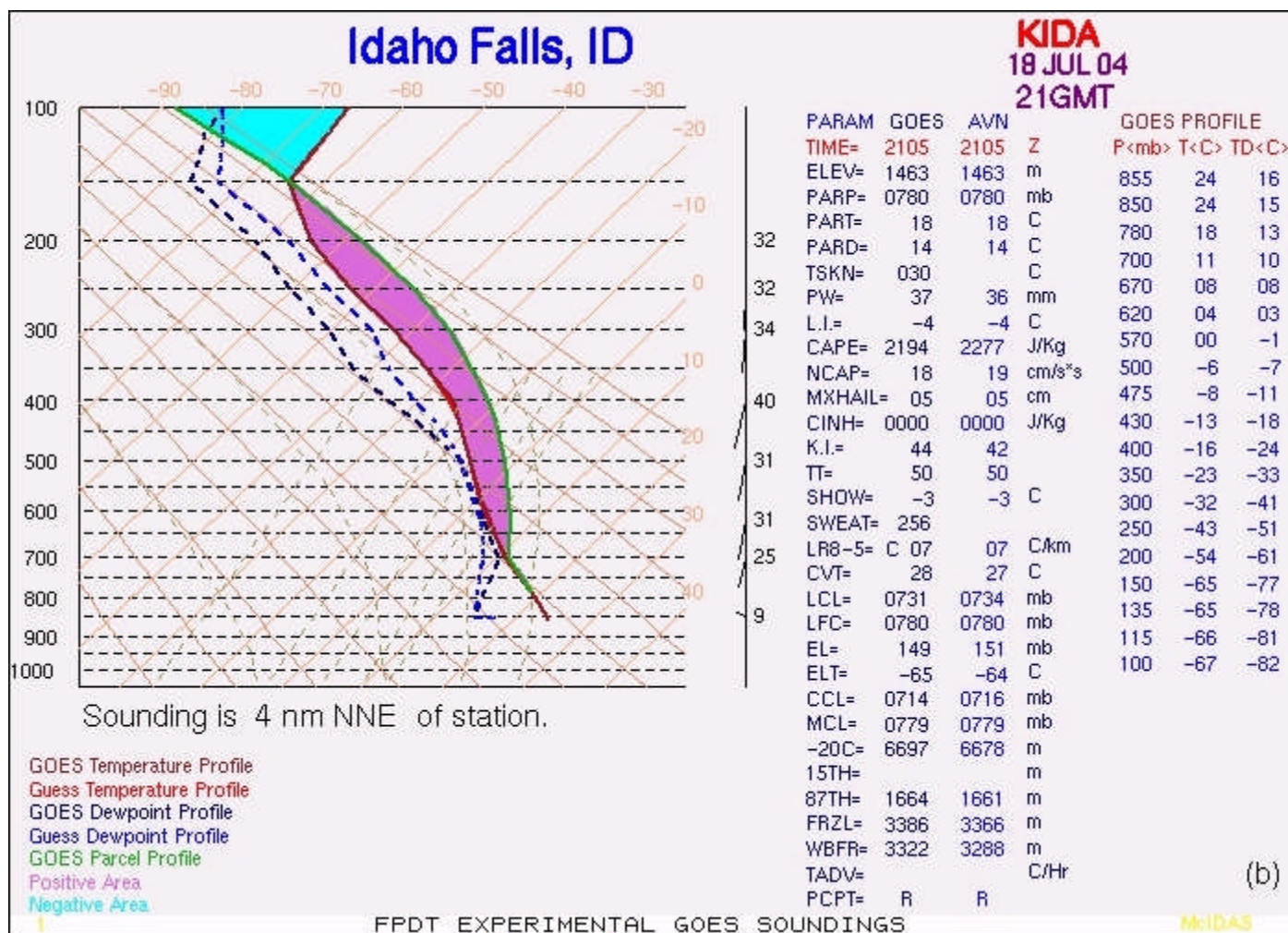


Figure 21b: NOAA GOES Sounding for Idaho Falls, Idaho : 2100 UTC 18 July 2004

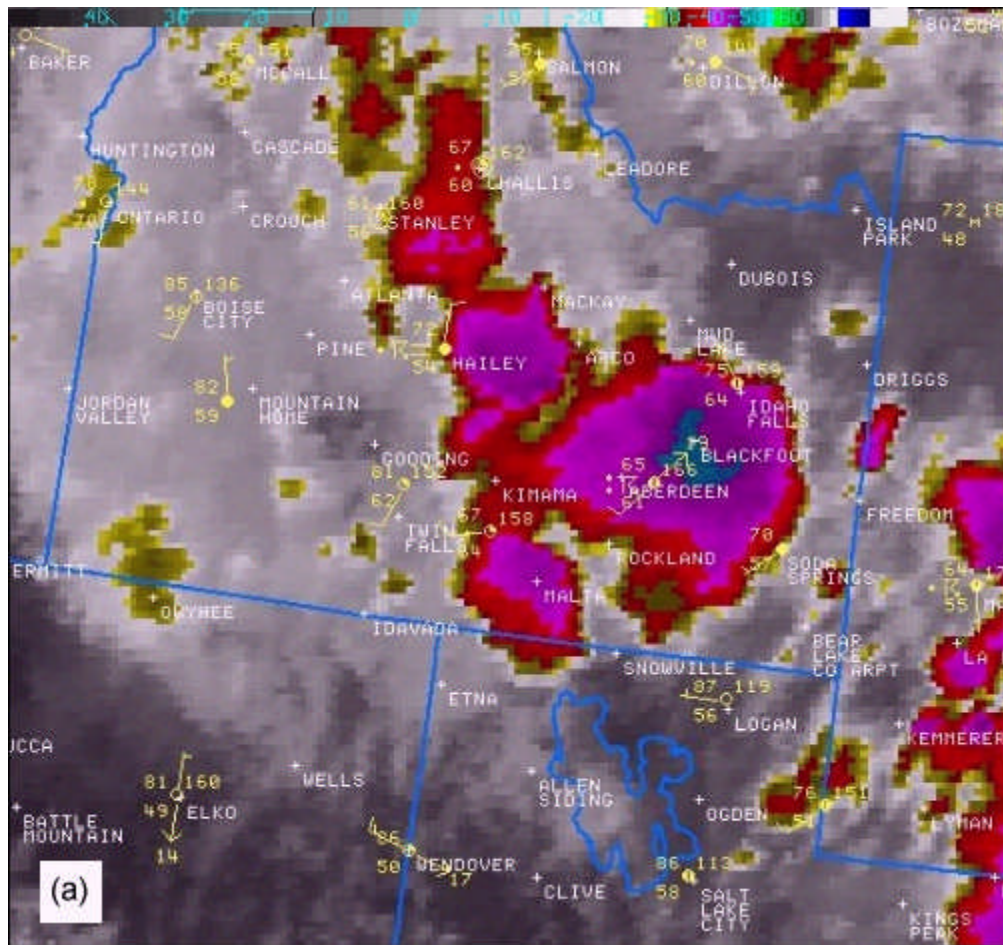


Figure 22a: NOAA GOES 4 km Infrared Satellite : 2200 UTC 18 July 2004
 NOAA NWS METAR Observations : 2200 UTC 18 July 2004

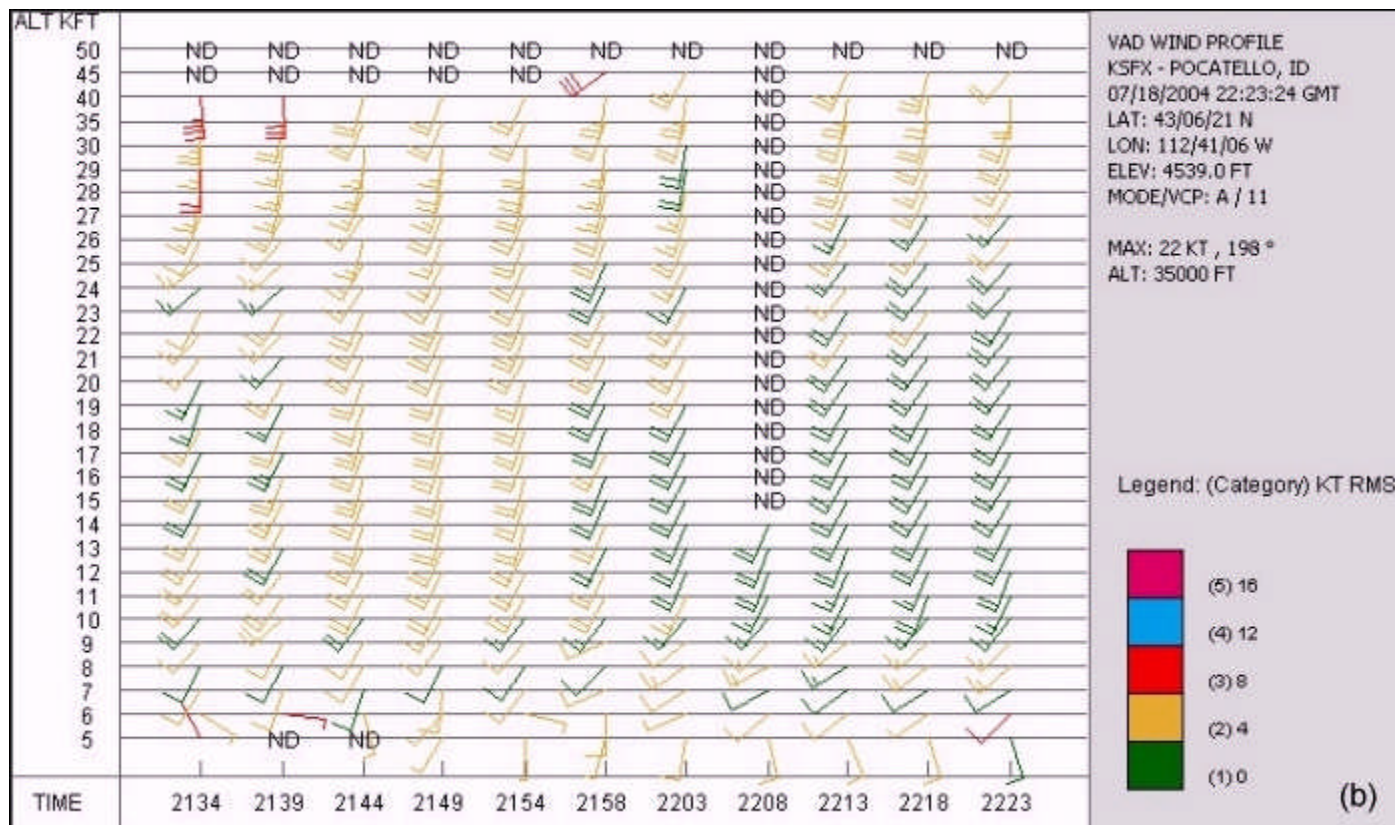


Figure 22b: KSPX WSR-88D VAD Wind Profile (knots) : [2134 UTC to 2223 UTC] 18 July 2004

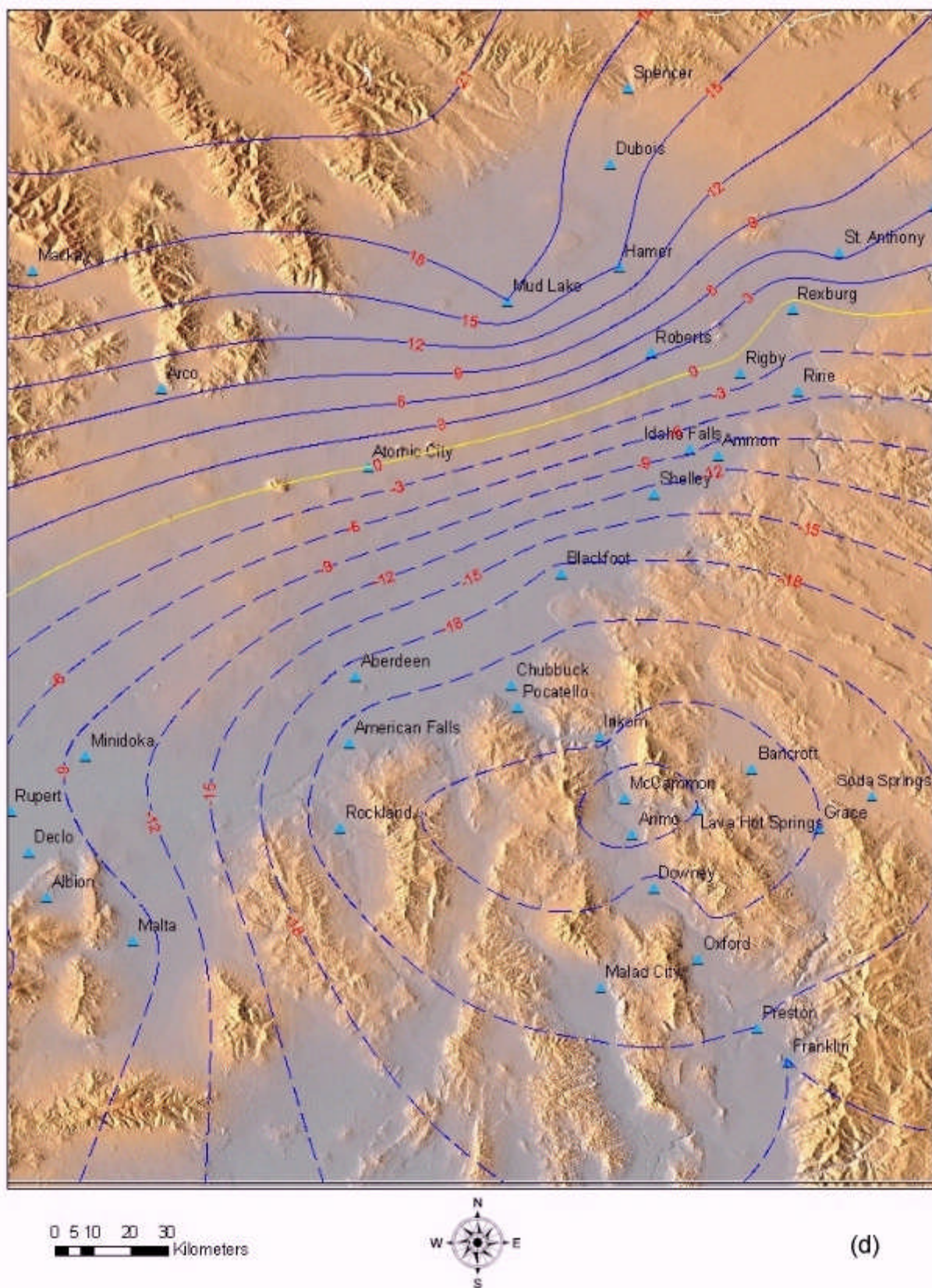


Figure 22d: MSAS Surface Moisture Flux Divergence ($\text{g} \cdot 12 \text{ hr} \cdot \text{kg}^{-1}$) : 2200 UTC 18 July 2004

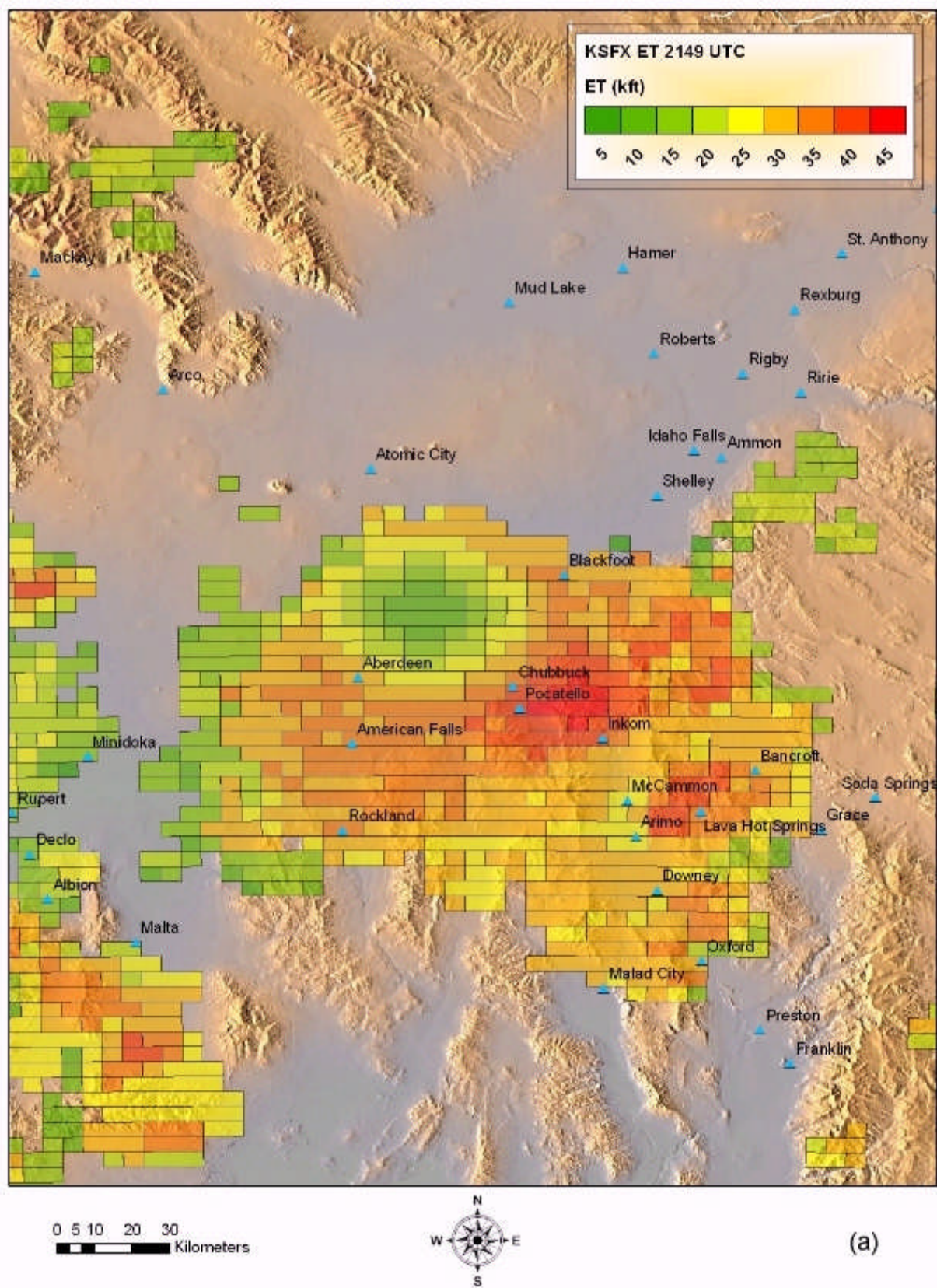


Figure 23a: KSFX WSR-88D Echo Tops (kft) : 2149 UTC 18 July 2004

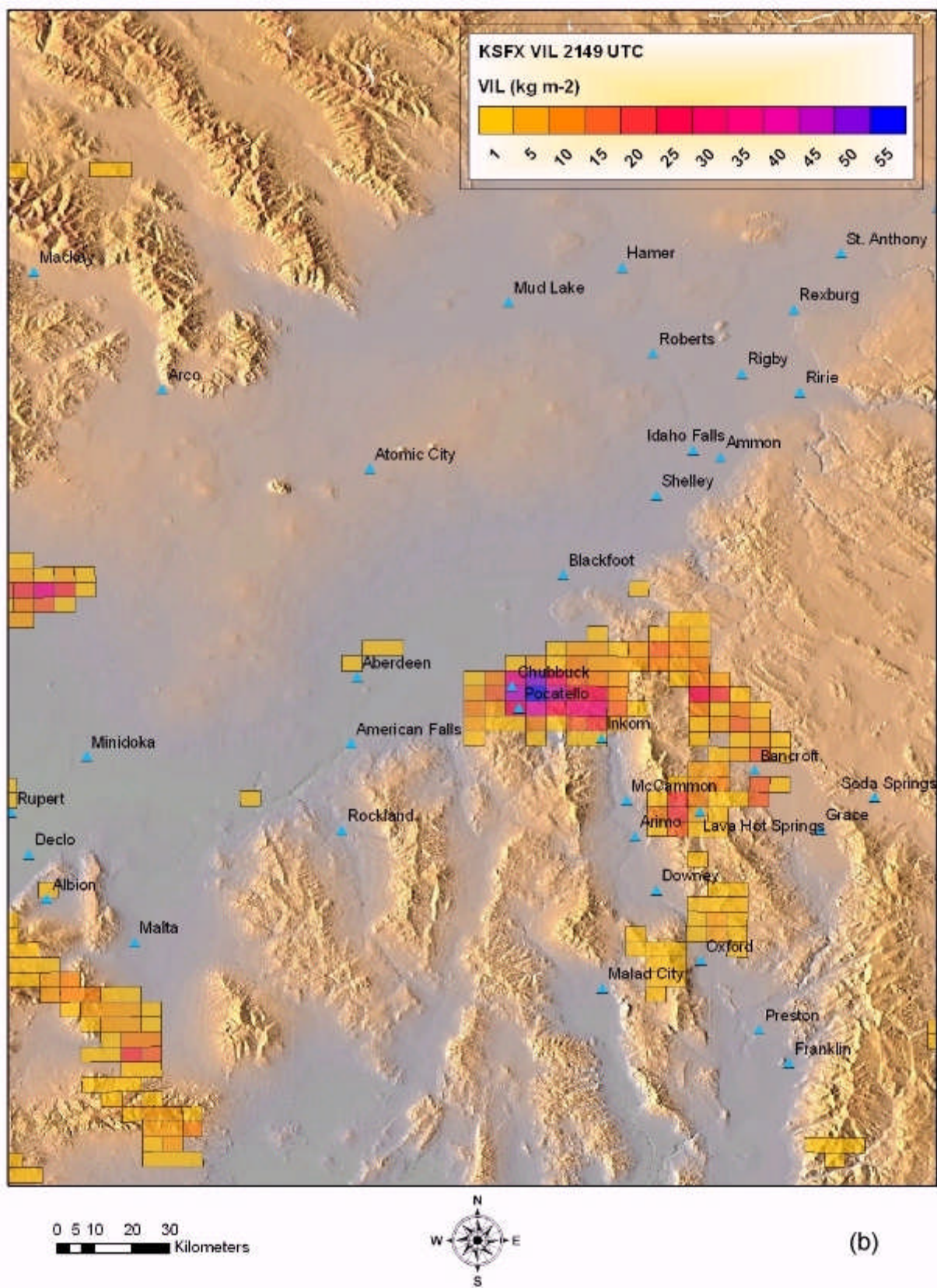


Figure 23b: KSFX WSR-88D Vertically Integrated Liquid (kg m^{-2}) : 2149 UTC 18 July 2004

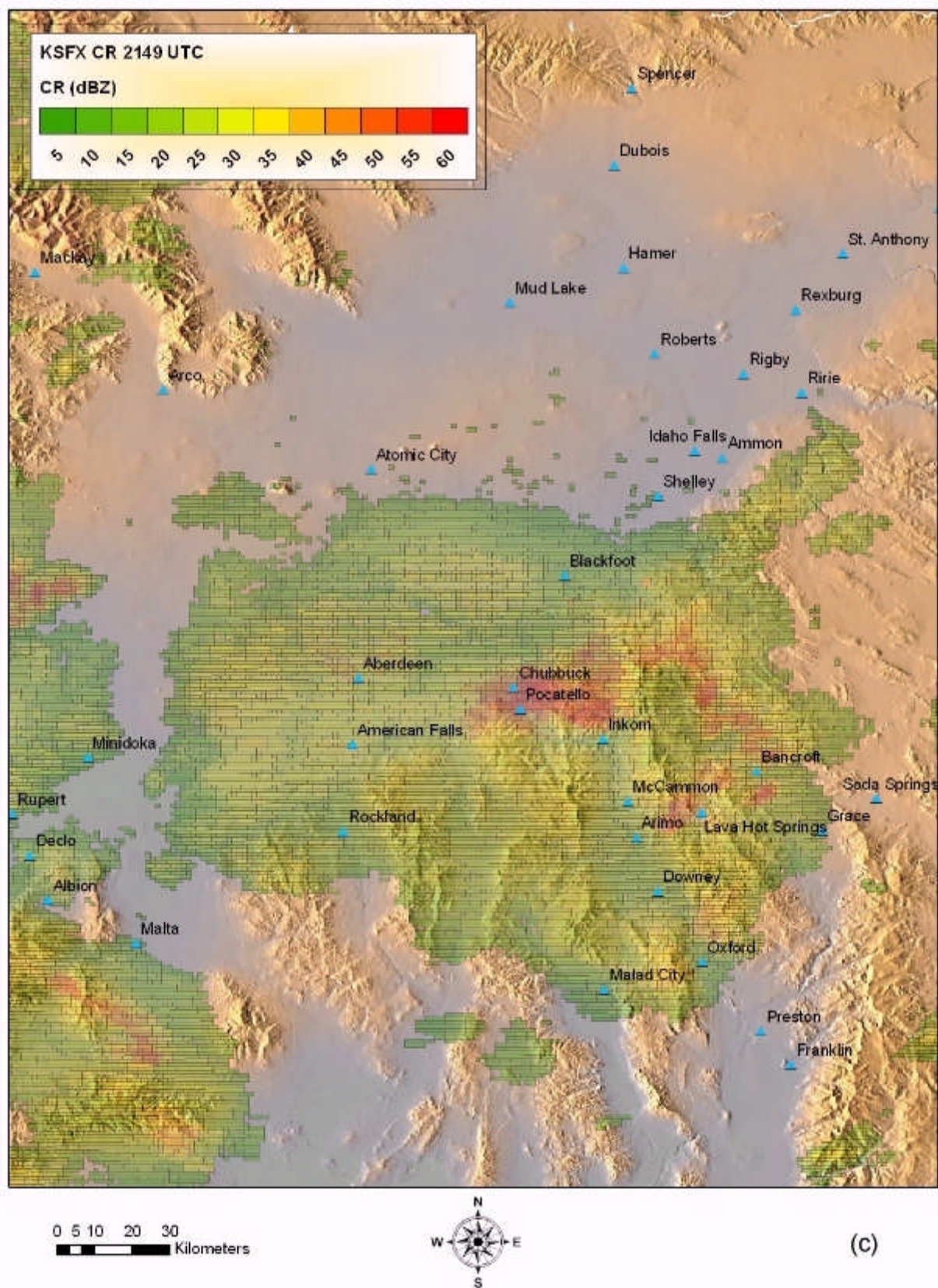


Figure 23c: KSFY WSR-88D Composite Reflectivity (dBZ) : 2149 UTC 18 July 2004

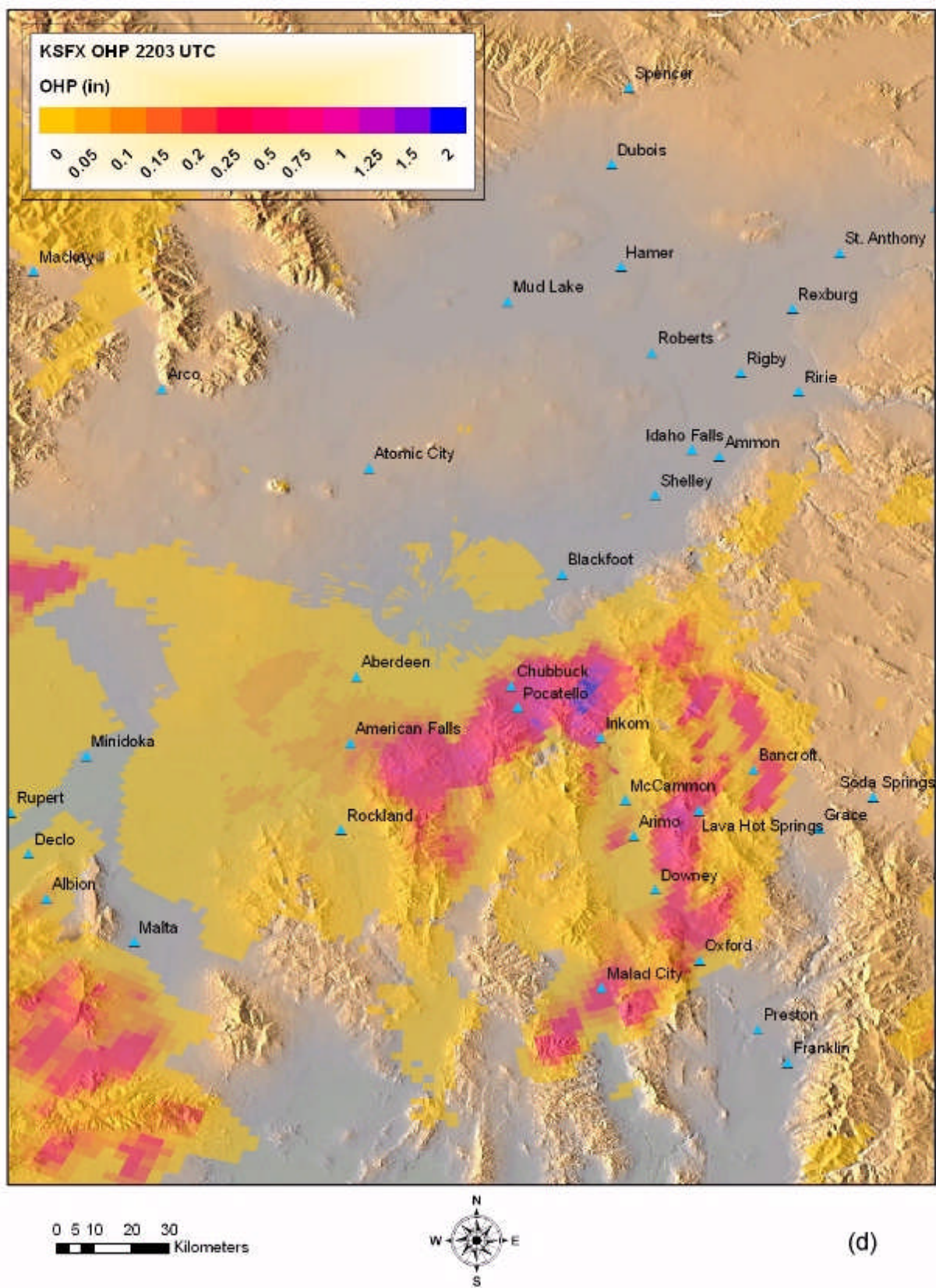


Figure 23d: KSFX WSR-88D One Hour Precipitation (inches) : 2203 UTC 18 July 2004

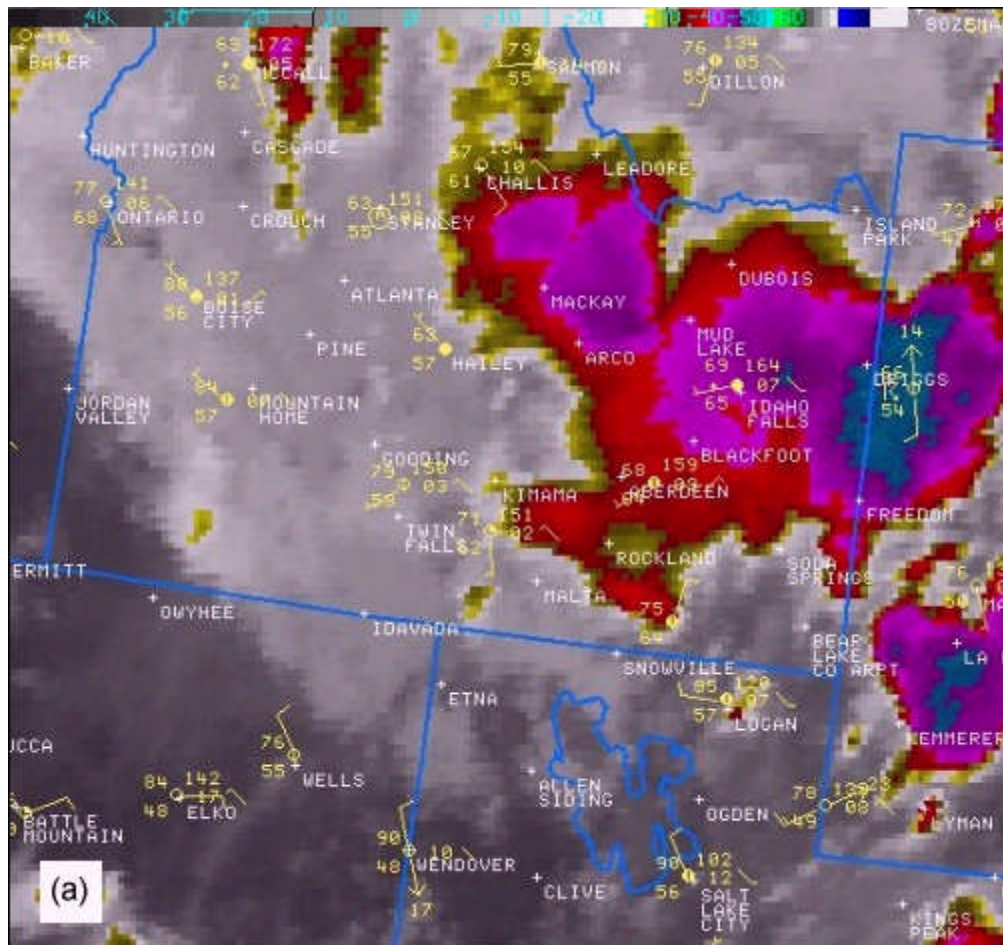


Figure 24a: NOAA GOES 4 km Infrared Satellite : 0000 UTC 19 July 2004
 NOAA NWS METAR Observations : 0000 UTC 19 July 2004

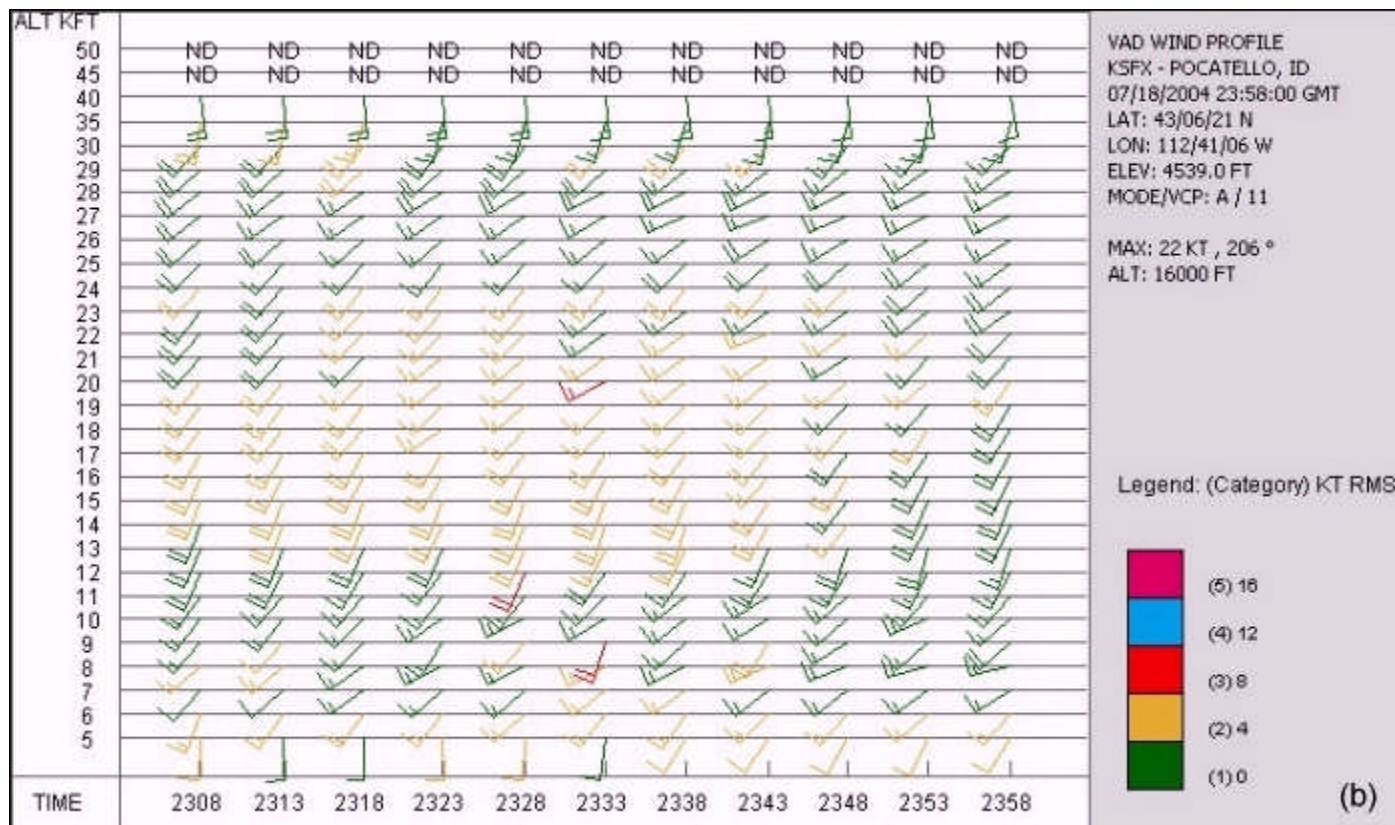


Figure 24b: KSPX WSR-88D VAD Wind Profile (knots) : [2308 UTC to 2358 UTC] 18 July 2004

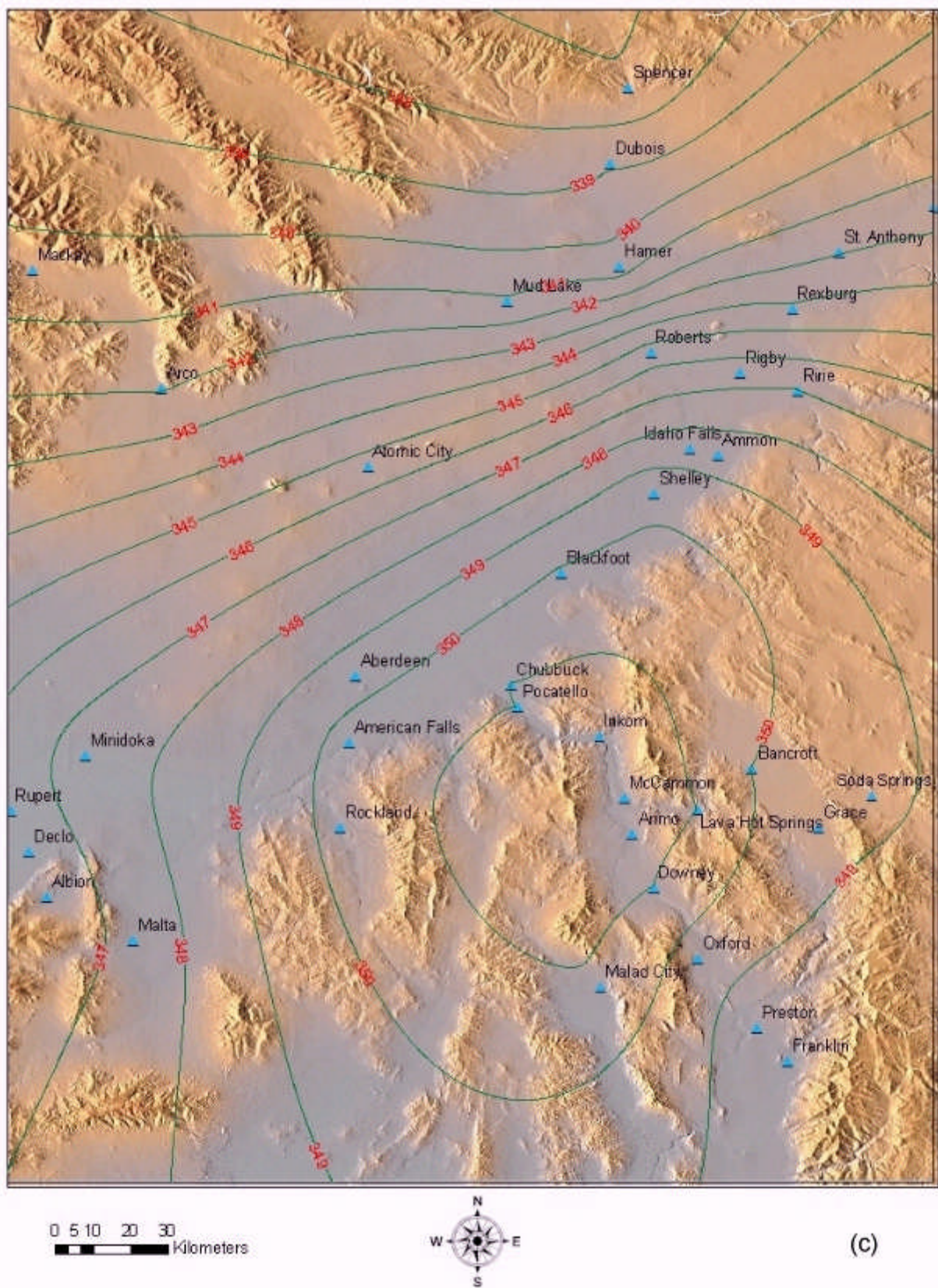


Figure 24c: MSAS Surface Equivalent Potential Temperature ($^{\circ}\text{K}$) : 0000 UTC 19 July 2004

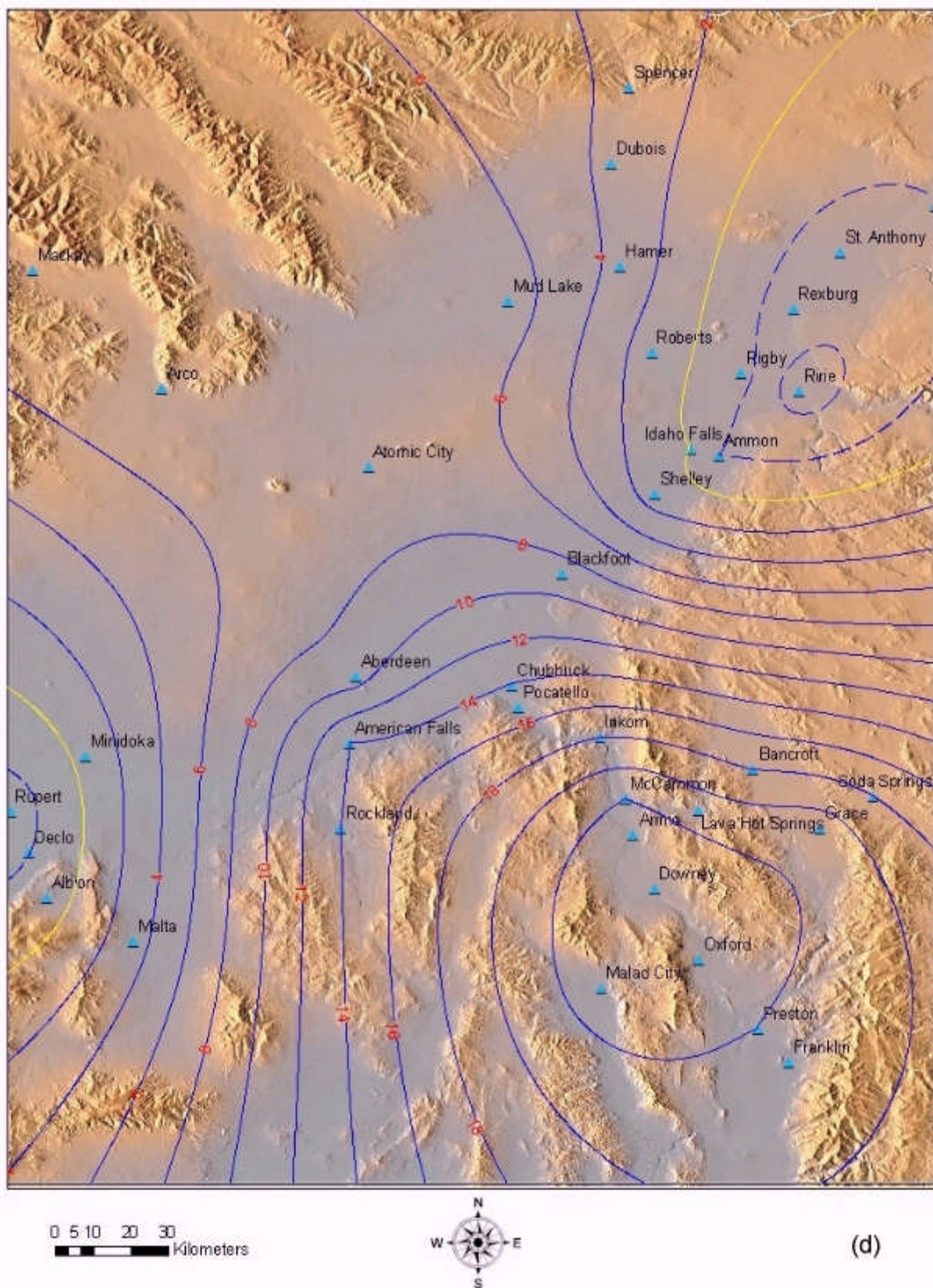


Figure 24d: MSAS Surface Moisture Flux Divergence ($\text{g} \cdot 12 \text{ hr} \cdot \text{kg}^{-1}$) : 0000 UTC 19 July 2004

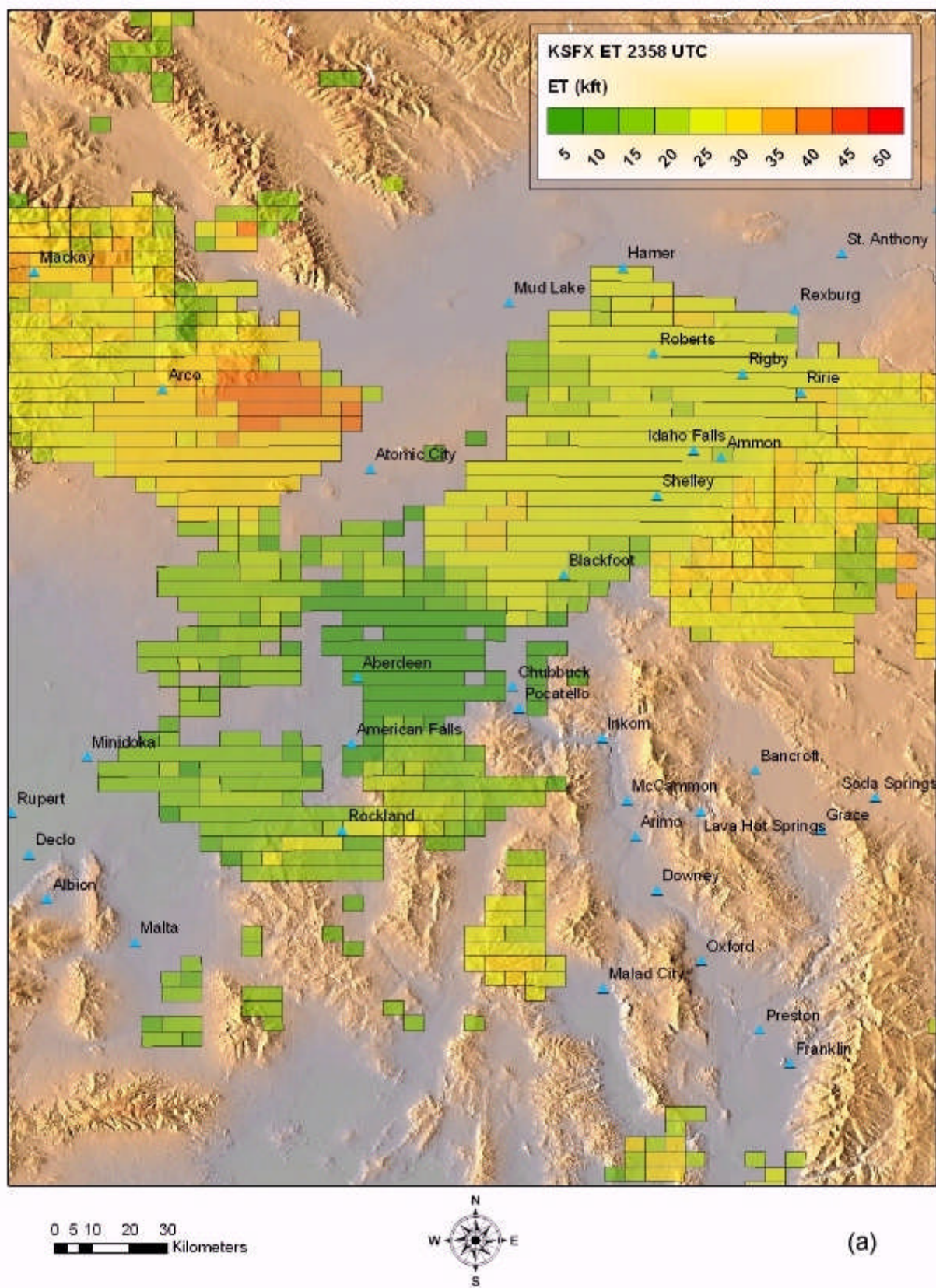


Figure 25a: KSFX WSR-88D Echo Tops (kft) : 2358 UTC 18 July 2004

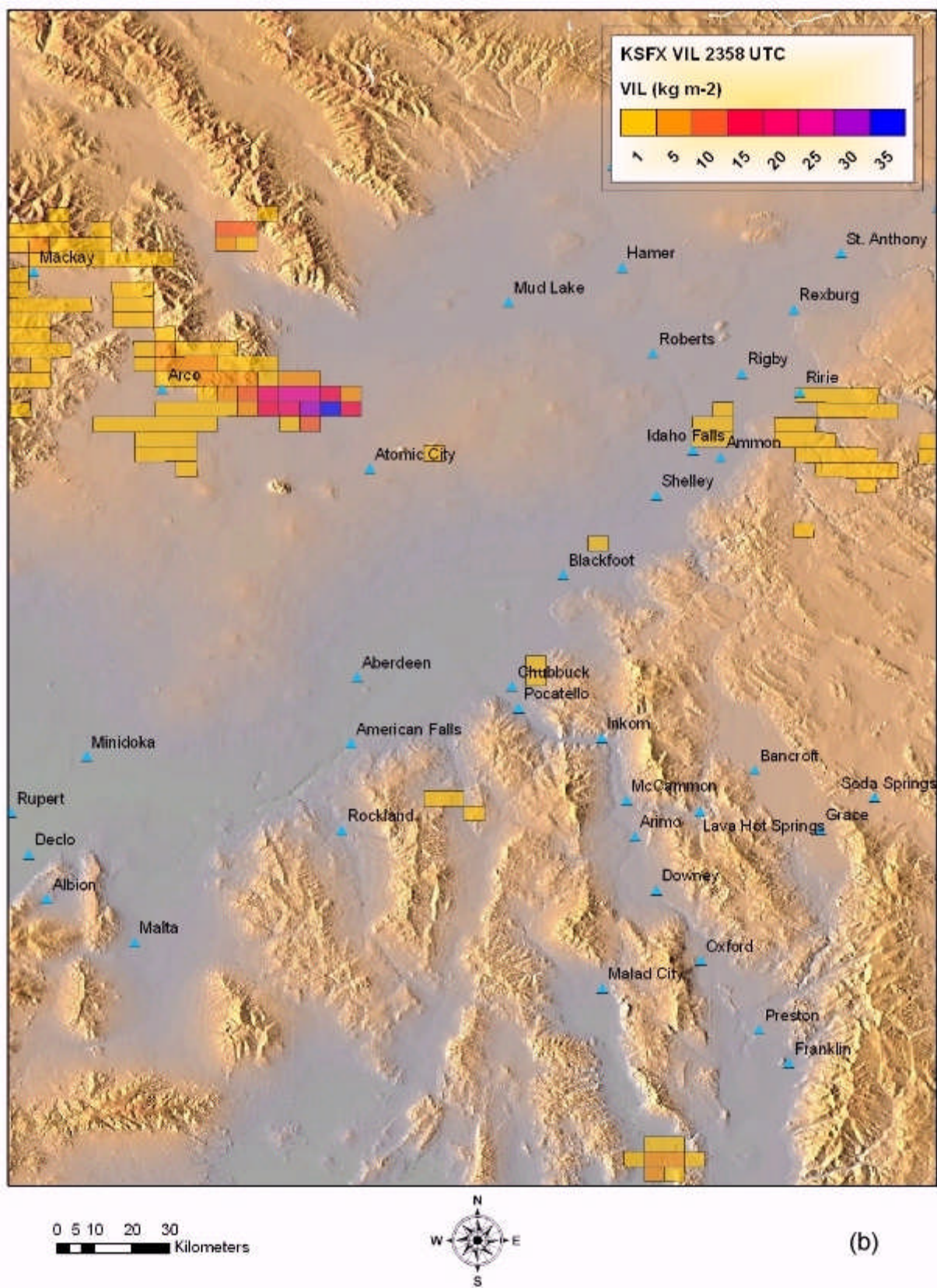


Figure 25b: KSFx WSR-88D Vertically Integrated Liquid (kg m^{-2}) : 2358 UTC 18 July 2004



Figure 25c: KSFX WSR-88D Composite Reflectivity (dBZ) : 2358 UTC 18 July 2004

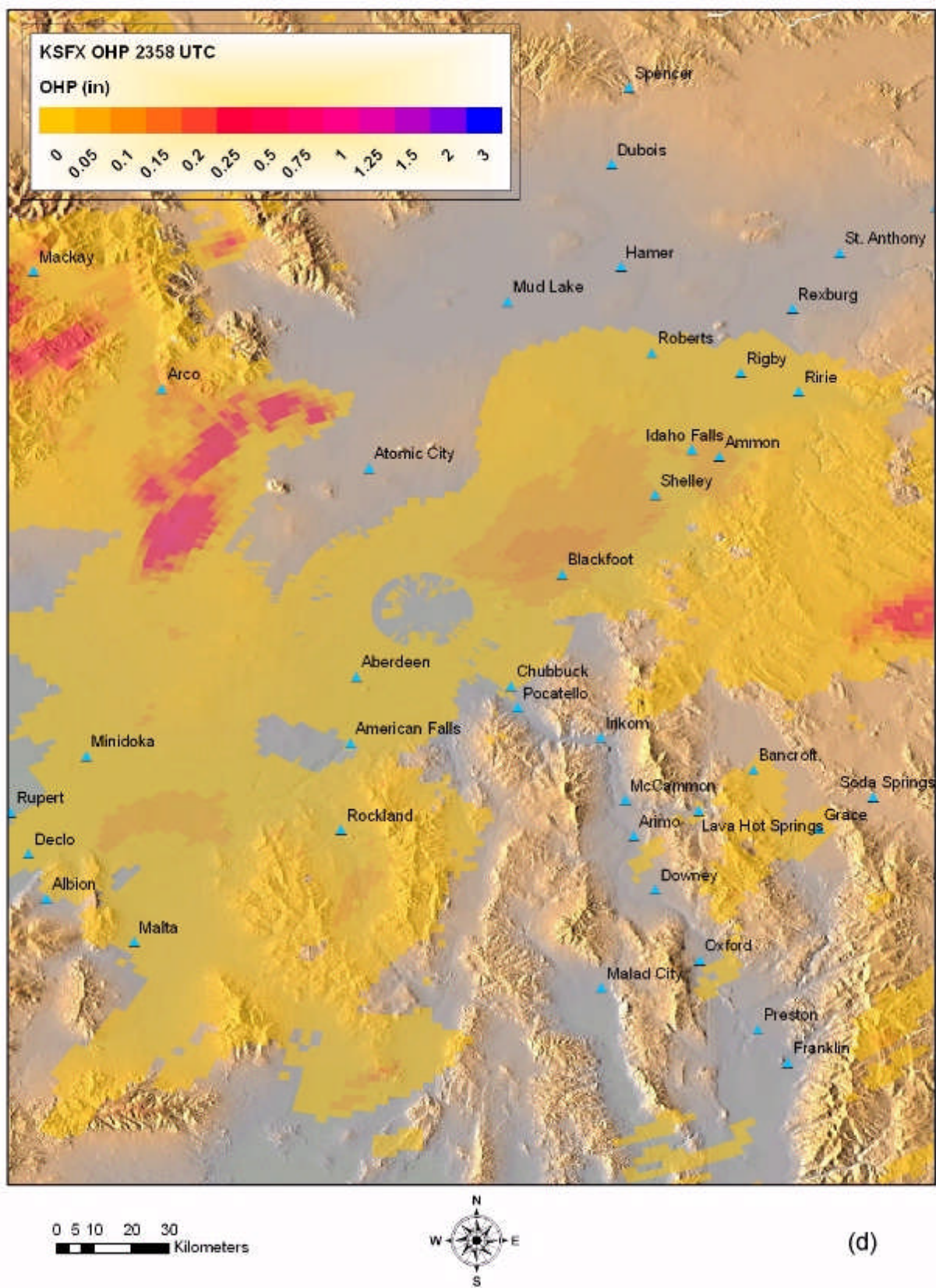


Figure 25d: KSFY WSR-88D One Hour Precipitation (inches) : 2358 UTC 18 July 2004

Flash Flood Event : 18 July 2004

Table 1 : Local Storm Reports

Time (UTC)	Event	Location	Comments
2045	Heavy Rains	American Falls	0.75 inches of rain in 30 minutes
2055	Heavy Rains	Rockland	1.00 inch of rain in 45 minutes
2105	Flash Flood	2 miles south of Rockland	Heavy rains and flooding along Highway 37
2143	Flash Flood	Pocatello	1.0 foot of water in Center Street Underpass
2143	Heavy Rains	Pocatello	1.90 inches of rain in 45 minutes
2150	Flash Flood	5 miles north of Rockland	2.0 feet of water on Highway 37 near Post 60
2155	Heavy Rains	1 mile east of Pocatello	0.50 inches of rain in 15 minutes
2155	Flash Flood	1 mile east of Pocatello	Street flooding along Pocatello Creek Road
2155	Heavy Rains	2 miles east of Pocatello	0.53 inches of rain in 30 minutes with dime size hail
2155	Flash Flood	Pocatello	Street flooding on Arthur Street
2155	Flash Flood	Pocatello	Mudslide near Idaho State University
2155	Flash Flood	Pocatello	Flooding with rocks and debris at Franklin High School
2230	Flash Flood	Pocatello	Major flooding at intersection of Oak Street and Yellowstone Avenue
2241	Flash Flood	Pocatello	Flooding on 8th Street

Flash Flood Event : 18 July 2004
Table 2 : Objective Forecast Guidance

Level Parameters

Index	Threshold	Source: Location(s)	Comments
Surface Equivalent Potential Temperature (θ_e)	$\theta_e > 350 \text{ }^\circ\text{K}$	MSAS: Ridge axis over Power and Bannock counties	θ_e maxima increases in coverage and intensity with time
Surface Moisture Flux Divergence ($\vec{\nabla} \cdot (q \cdot \mathbf{V}_h)$)	$\vec{\nabla} \cdot (q \cdot \mathbf{V}_h) < -15 \text{ g} \cdot 12 \text{ hr} \cdot \text{kg}^{-1}$	MSAS: Minima over Power and Bannock counties	$\vec{\nabla} \cdot (q \cdot \mathbf{V}_h)$ minima superimposed over θ_e maxima

Layer Parameters

Index	Threshold	Source: Location(s)	Comments
Precipitable Water (PW)	PW > 1.20 inches	Atmospheric Soundings: BOI, LKN, SLC, PIH, IDA	Deep moist layer above ~700 mb Warm cloud layer depth > 1.5 km
Convective Available Potential Energy (CAPE)	CAPE > 1300 J kg ⁻¹ CAPE < 2200 J kg ⁻¹	NOAA GOES Soundings: PIH, IDA	Skinny CAPE for high precipitation efficiency of liquid water droplets
Radial Velocity (V_r)	$V_r < 20$ knots (through deep layer)	KSFX WSR-88D VWP: RDA tower	Wind profile exhibits low wind speed shear and small wind directional shear (with altitude)

