Abstract

Seasonal cycles of precipitation are documented for eastern Idaho using observed National Weather Service (NWS) climate station data available from the NOAA/National Climatic Data Center (NCDC) in Asheville, North Carolina. In order to better detect the seasonal precipitation patterns in the mountains of eastern Idaho, this study further utilized data obtained from 33 automated SNOTEL sites archived at the National Resources Conservation Service (NRCS). Harmonic analysis is applied to both data sets, identifying seasonal variabilities in their precipitation time series and associated climate regimes in eastern Idaho. The arithmetic means, standard deviations, percentage contributions of six harmonic amplitudes and harmonic phase values are computed for the station network. Cold season first harmonic maxima related to Pacific cyclonic controls are located in the Magic Valley, west Central Mountains, and Upper Snake Highlands while warm season maxima influenced by convection occur over the remainder of the Central Highlands. A transition in climate regimes is apparent in the Lower Snake River Plain (LSRP) with dominant first harmonic amplitudes replaced by strong second harmonic values in the Upper Snake River Plain (USR). A large area of prominent third harmonic amplitudes, possibly linked to large-scale topographic forcing, is observed from the eastern part of the USRP to the Idaho-Wyoming border and extending south into the Caribou Highlands. Southeast of the Central Mountains, well-defined fourth harmonic amplitudes are located near the intersection of the Big and Little Lost River Valleys and the USRP where local upslope and convergence are factors in producing precipitation. Harmonic analysis will assist operational forecasters in identifying the phase, strength, and location of seasonal precipitation regimes over eastern Idaho.

1. Introduction

This study employs mean monthly precipitation time series across the intermountain West for eastern Idaho and the contiguous areas of Montana, Utah, and Wyoming to elucidate seasonal changes in rainfall and snowfall patterns. Mean monthly precipitation normals are derived from 30 year (1961 to 1990) National Weather Service (NWS) data and 10 to 15 year National Resources Conservation Service (NRCS) SNOTEL data. Tables 1a, 1b, and 1c provide a complete listing of the NWS and NRCS climate stations included in this analysis, indexed by acronym, name, longitude, latitude, and elevation.

Harmonic analysis is applied to the NWS and NRCS mean monthly precipitation time series data of each station. This technique has several advantages over using common statistics. The annual march or time series for each station can be deduced into an arithmetic mean plus several harmonic time series. The harmonics allow a quantifiable way of delineating the different variabilities or tendencies in the data. These tendencies may be categorized as annual (one maximum and one minimum), semi-annual (two maxima and two minima) and so on. The tendencies are classified by two parameters: harmonic amplitude and phase. The harmonic amplitude indicates the strength of the particular tendency while the phase indicates the time the harmonic reaches a maximum or minimum. Transitions in phase corresponding to large harmonic amplitudes represent seasonal changes in precipitation regimes. However, harmonics do not handle step functions adequately and abrupt changes between seasons can sometimes occur in the phase charts. Nevertheless, the amplitude and phase trends in the time series data can easily be detected both numerically and graphically by using harmonic analysis.

2. Eastern Idaho Terrain Features

Figure 1 displays the topography map of eastern Idaho with geographical regions indexed by number. NWS and NRCS station identifiers, located by the dashed meridians and parallels, are illustrated on a map of eastern Idaho in Fig. 2. The terrain of eastern Idaho is largely influenced by the Snake River Plain (SRP) which is approximately 100 km wide, oriented from southwest to northeast with a gradual increase in elevation from ~1.3 km near Minidoka (MIN) (in the Magic Valley) to ~1.5 km near St. Anthony 1 WNW (STA). The region of the SRP north of Blackfoot 2 SSW (BLK) to Arco 3 SW (ARC) is defined as the Upper Snake River Plain (USRP), and the region south to American Falls 1 SW (AMF) and MIN is defined as the Lower Snake River Plain (LSRP). Other important geographical features include: the Upper Snake and Caribou Highlands (average elevation ~2.0 km), which define the northeast and southeast boundary of the USRP and LSRP, respectively; the Central Mountains (average elevation ~3.0 km) which define the west and northwest boundary of the USRP and LSRP; and the relatively deep and narrow Central Mountain Valleys (Big Lost River, Little Lost River, and Birch Creek) which are oriented from northwest to southeast and open onto the USRP. These Central Mountain Valleys
Table 1a. NWS Climate Stations in Eastern Idaho

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Station Name</th>
<th>Longitude (W)</th>
<th>Latitude (N)</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABD</td>
<td>Aberdeen Experimental Station</td>
<td>112.83</td>
<td>42.95</td>
<td>1342</td>
</tr>
<tr>
<td>AMF</td>
<td>American Falls 1 SW</td>
<td>112.87</td>
<td>42.78</td>
<td>1316</td>
</tr>
<tr>
<td>ARB</td>
<td>Arbon 2 NW</td>
<td>112.50</td>
<td>42.50</td>
<td>1576</td>
</tr>
<tr>
<td>ARC</td>
<td>Arco 3 SW</td>
<td>113.33</td>
<td>43.60</td>
<td>1624</td>
</tr>
<tr>
<td>ASH</td>
<td>Ashton</td>
<td>111.45</td>
<td>44.06</td>
<td>1603</td>
</tr>
<tr>
<td>BLK</td>
<td>Blackfoot 2 SSW</td>
<td>112.35</td>
<td>43.17</td>
<td>1368</td>
</tr>
<tr>
<td>BLS</td>
<td>Bliss 4 NW</td>
<td>115.00</td>
<td>42.95</td>
<td>998</td>
</tr>
<tr>
<td>BYI</td>
<td>Burley FAA Airport</td>
<td>113.77</td>
<td>42.53</td>
<td>1267</td>
</tr>
<tr>
<td>CHA</td>
<td>Challis</td>
<td>114.23</td>
<td>44.50</td>
<td>1577</td>
</tr>
<tr>
<td>CHL</td>
<td>Chilly Barton Flat</td>
<td>113.52</td>
<td>43.98</td>
<td>1906</td>
</tr>
<tr>
<td>COB</td>
<td>Cobalt</td>
<td>114.23</td>
<td>45.08</td>
<td>1527</td>
</tr>
<tr>
<td>CRA</td>
<td>Craters of the Moon Park</td>
<td>113.57</td>
<td>43.47</td>
<td>1797</td>
</tr>
<tr>
<td>DRG</td>
<td>Driggs</td>
<td>111.12</td>
<td>43.73</td>
<td>1879</td>
</tr>
<tr>
<td>DUB</td>
<td>Dubois Experimental Station</td>
<td>112.20</td>
<td>44.25</td>
<td>1661</td>
</tr>
<tr>
<td>FFD</td>
<td>Fairfield Ranger Station</td>
<td>114.78</td>
<td>43.35</td>
<td>1544</td>
</tr>
<tr>
<td>FOH</td>
<td>Fort Hall Indian Agency</td>
<td>112.43</td>
<td>43.03</td>
<td>1359</td>
</tr>
<tr>
<td>GRA</td>
<td>Grace</td>
<td>111.73</td>
<td>42.58</td>
<td>1692</td>
</tr>
<tr>
<td>GRS</td>
<td>Grouse</td>
<td>113.62</td>
<td>43.70</td>
<td>1859</td>
</tr>
<tr>
<td>SUN</td>
<td>Halley 3 NW</td>
<td>114.33</td>
<td>43.57</td>
<td>1653</td>
</tr>
<tr>
<td>HAM</td>
<td>Hamer 4 NW</td>
<td>112.27</td>
<td>43.97</td>
<td>1438</td>
</tr>
<tr>
<td>HZN</td>
<td>Hazleton</td>
<td>114.13</td>
<td>42.60</td>
<td>1238</td>
</tr>
<tr>
<td>HIL</td>
<td>Hill City 1 W</td>
<td>115.05</td>
<td>43.30</td>
<td>1524</td>
</tr>
<tr>
<td>HLS</td>
<td>Hollister</td>
<td>114.57</td>
<td>43.35</td>
<td>1379</td>
</tr>
<tr>
<td>HOW</td>
<td>Howie</td>
<td>113.00</td>
<td>43.78</td>
<td>1469</td>
</tr>
<tr>
<td>ID1</td>
<td>Idaho Falls 2 ESE</td>
<td>112.02</td>
<td>43.48</td>
<td>1456</td>
</tr>
<tr>
<td>ID2</td>
<td>Idaho Falls 16 SE</td>
<td>111.78</td>
<td>43.35</td>
<td>1783</td>
</tr>
<tr>
<td>ID3</td>
<td>Idaho Falls FAA Airport</td>
<td>112.07</td>
<td>43.52</td>
<td>1442</td>
</tr>
<tr>
<td>ID4</td>
<td>Idaho Falls 46 W</td>
<td>112.95</td>
<td>43.37</td>
<td>1505</td>
</tr>
<tr>
<td>ISL</td>
<td>Island Park</td>
<td>111.37</td>
<td>44.42</td>
<td>1917</td>
</tr>
<tr>
<td>JRM</td>
<td>Jerome</td>
<td>114.52</td>
<td>42.73</td>
<td>1140</td>
</tr>
<tr>
<td>LIF</td>
<td>Lifton Pumping Station</td>
<td>111.30</td>
<td>42.12</td>
<td>1806</td>
</tr>
<tr>
<td>MAC</td>
<td>Mackay Ranger Station</td>
<td>113.62</td>
<td>43.92</td>
<td>1797</td>
</tr>
<tr>
<td>MLD</td>
<td>Malad City</td>
<td>112.28</td>
<td>42.17</td>
<td>1362</td>
</tr>
<tr>
<td>MAL</td>
<td>Malta 2 E</td>
<td>113.28</td>
<td>42.30</td>
<td>1384</td>
</tr>
<tr>
<td>MAY</td>
<td>May</td>
<td>113.92</td>
<td>44.60</td>
<td>1558</td>
</tr>
<tr>
<td>MIN</td>
<td>Minidoka Dam</td>
<td>113.48</td>
<td>42.67</td>
<td>1280</td>
</tr>
<tr>
<td>MTP</td>
<td>Montpelier Ranger Station</td>
<td>111.30</td>
<td>42.32</td>
<td>1817</td>
</tr>
<tr>
<td>OAK</td>
<td>Oakley</td>
<td>113.88</td>
<td>42.23</td>
<td>1402</td>
</tr>
<tr>
<td>PAL</td>
<td>Palisades</td>
<td>111.23</td>
<td>43.37</td>
<td>1641</td>
</tr>
<tr>
<td>PAU</td>
<td>Paul 1 ENE</td>
<td>113.75</td>
<td>42.62</td>
<td>1283</td>
</tr>
<tr>
<td>PIC</td>
<td>Picabo</td>
<td>114.07</td>
<td>43.30</td>
<td>1486</td>
</tr>
<tr>
<td>PIN</td>
<td>Pocatello WSO Airport</td>
<td>112.60</td>
<td>42.92</td>
<td>1358</td>
</tr>
<tr>
<td>RIC</td>
<td>Richfield</td>
<td>114.15</td>
<td>43.06</td>
<td>1312</td>
</tr>
<tr>
<td>SMN</td>
<td>Salmon KSRA</td>
<td>113.90</td>
<td>45.18</td>
<td>1998</td>
</tr>
<tr>
<td>SHO</td>
<td>Shoshone 1 WNW</td>
<td>114.43</td>
<td>42.97</td>
<td>1204</td>
</tr>
<tr>
<td>STA</td>
<td>Saint Anthony 1 WNW</td>
<td>111.72</td>
<td>43.97</td>
<td>1509</td>
</tr>
<tr>
<td>STN</td>
<td>Stanley</td>
<td>114.93</td>
<td>44.22</td>
<td>1911</td>
</tr>
<tr>
<td>SWV</td>
<td>Swan Valley 2 E</td>
<td>111.30</td>
<td>43.45</td>
<td>1634</td>
</tr>
<tr>
<td>TET</td>
<td>Teton Experimental Station</td>
<td>111.27</td>
<td>43.85</td>
<td>1881</td>
</tr>
</tbody>
</table>

Table 1b. NWS Climate Stations in Montana, Utah, and Wyoming

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Station Name</th>
<th>Longitude (W)</th>
<th>Latitude (N)</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLN</td>
<td>Dillon Airport, MT</td>
<td>112.55</td>
<td>45.25</td>
<td>1590</td>
</tr>
<tr>
<td>LAK</td>
<td>Lakeview, MT</td>
<td>111.80</td>
<td>44.60</td>
<td>2045</td>
</tr>
<tr>
<td>LIM</td>
<td>Lima, MT</td>
<td>112.58</td>
<td>44.65</td>
<td>1912</td>
</tr>
<tr>
<td>MOD</td>
<td>Mondia, MT</td>
<td>112.32</td>
<td>44.57</td>
<td>2068</td>
</tr>
<tr>
<td>WEY</td>
<td>West Yellowstone, MT</td>
<td>111.10</td>
<td>44.65</td>
<td>2030</td>
</tr>
<tr>
<td>GAR</td>
<td>Garland, UT</td>
<td>112.17</td>
<td>41.73</td>
<td>1326</td>
</tr>
<tr>
<td>GRC</td>
<td>Grouse Creek, UT</td>
<td>113.88</td>
<td>41.72</td>
<td>1622</td>
</tr>
<tr>
<td>LKN</td>
<td>Laketown, UT</td>
<td>111.32</td>
<td>41.62</td>
<td>1822</td>
</tr>
<tr>
<td>LOG</td>
<td>Logan, UT</td>
<td>111.80</td>
<td>41.75</td>
<td>1460</td>
</tr>
<tr>
<td>PFK</td>
<td>Park Valley, UT</td>
<td>113.33</td>
<td>41.82</td>
<td>1689</td>
</tr>
<tr>
<td>RCH</td>
<td>Richmond, UT</td>
<td>111.82</td>
<td>41.90</td>
<td>1426</td>
</tr>
<tr>
<td>SNW</td>
<td>Snowville, UT</td>
<td>112.72</td>
<td>41.97</td>
<td>1390</td>
</tr>
<tr>
<td>AFT</td>
<td>Afton, WY</td>
<td>110.93</td>
<td>42.73</td>
<td>1893</td>
</tr>
<tr>
<td>ALT</td>
<td>Alta 1 NWY, WY</td>
<td>111.03</td>
<td>43.78</td>
<td>1960</td>
</tr>
<tr>
<td>JAC</td>
<td>Jackson, WY</td>
<td>110.77</td>
<td>43.48</td>
<td>1899</td>
</tr>
<tr>
<td>MOS</td>
<td>Moose, WY</td>
<td>110.72</td>
<td>43.67</td>
<td>1972</td>
</tr>
<tr>
<td>YPK</td>
<td>Yellowstone Park, WY</td>
<td>110.70</td>
<td>44.97</td>
<td>1899</td>
</tr>
</tbody>
</table>

3. Methodology

Horn and Bryson (1960) used harmonic analysis to study the seasonal cycles in precipitation over the conterminous United States using station data from the period 1921 to 1950. Fitzpatrick (1964) and Hastenrath (1968) used the method to examine rainfall trends over Australia and Central America, respectively. Moreover, Scott and Shulman (1979) and Winkler et al. (1988) applied harmonic analysis to observed precipitation in the United States. On a much smaller geographical scale, this technique was used to examine diurnal precipitation signatures in the Salt Lake Valley (Asthling 1984). Kirkyla and Hameed (1989) investigated seasonal cycles of precipitation using gridded precipitation data both from observations and the 1 x CO2 run of the Oregon State University Global General Circulation Model (OSU GCM) for the 48 conterminous United States and other geographical areas (Potter and Gates 1984). A follow-up study by Andrea et al. (1990) utilized harmonic analysis to analyze the CO2-induced precipitation perturbations in North America and Africa using the OSU GCM.

This technique uses sine and cosine trigonometric functions to explain the finite time series periodic nature of temporally varying parameters (Panofsky and Brier 1958; Wilks 1995). Summing over the k=1,2,3,...,N/2 harmonics, the net equation for the time series becomes:

$$Y(t) = Y_0 + \sum A_k \cos(360N(t-t_k)/2P)$$  \hspace{1cm} (1)

where, Y(t) is the sum of Y0, the arithmetic mean monthly value of the N observations, plus a time series of k harmonics; P is the total period covered by the harmonics. Each of the k harmonics (with frequency k) has an Ak net harmonic amplitude and a time, tk, when this amplitude reaches its maximum value (t=tk). The

decrease in elevation from ~1.9 km at their northwest end to ~1.6 km at the opening to the USRP. Data collection sites are generally collocated with populated valley locations, but terrain heights go well above 2.0 km in most mountainous areas in eastern Idaho (Fig. 1).
Table 1c. NRCS SNOTEL Stations in Eastern Idaho

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Station Name</th>
<th>Longitude (W)</th>
<th>Latitude (N)</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEC</td>
<td>Bear Canyon</td>
<td>113.93</td>
<td>43.75</td>
<td>2409</td>
</tr>
<tr>
<td>BRS</td>
<td>Bosteter Ranger Station</td>
<td>114.18</td>
<td>42.17</td>
<td>2287</td>
</tr>
<tr>
<td>CRC</td>
<td>Crab Creek</td>
<td>112.00</td>
<td>44.43</td>
<td>2091</td>
</tr>
<tr>
<td>DLS</td>
<td>Dollar Hide Summit</td>
<td>114.67</td>
<td>43.80</td>
<td>2567</td>
</tr>
<tr>
<td>EMS</td>
<td>Emigrant Summit</td>
<td>111.57</td>
<td>42.37</td>
<td>2253</td>
</tr>
<tr>
<td>FBS</td>
<td>Franklin Basin</td>
<td>111.60</td>
<td>42.05</td>
<td>2491</td>
</tr>
<tr>
<td>GNA</td>
<td>Galena</td>
<td>114.67</td>
<td>43.88</td>
<td>2268</td>
</tr>
<tr>
<td>GLS</td>
<td>Galena Summit</td>
<td>114.72</td>
<td>43.85</td>
<td>2677</td>
</tr>
<tr>
<td>GAR</td>
<td>Garfield Ranger Station</td>
<td>113.93</td>
<td>43.62</td>
<td>2000</td>
</tr>
<tr>
<td>GIV</td>
<td>Giveout</td>
<td>111.17</td>
<td>42.42</td>
<td>2113</td>
</tr>
<tr>
<td>HCK</td>
<td>Hills Creek</td>
<td>113.47</td>
<td>44.02</td>
<td>2439</td>
</tr>
<tr>
<td>HOC</td>
<td>Howel Canyon</td>
<td>113.62</td>
<td>42.32</td>
<td>2433</td>
</tr>
<tr>
<td>HUM</td>
<td>Humboldt Gulch</td>
<td>115.78</td>
<td>47.53</td>
<td>1296</td>
</tr>
<tr>
<td>HYN</td>
<td>Hyndman</td>
<td>114.17</td>
<td>43.70</td>
<td>2268</td>
</tr>
<tr>
<td>IPR</td>
<td>Island Park Ranger Station</td>
<td>111.38</td>
<td>44.42</td>
<td>1918</td>
</tr>
<tr>
<td>LOK</td>
<td>Lookout</td>
<td>115.70</td>
<td>47.45</td>
<td>1567</td>
</tr>
<tr>
<td>LOL</td>
<td>Lost Lake</td>
<td>115.97</td>
<td>47.08</td>
<td>1863</td>
</tr>
<tr>
<td>LWD</td>
<td>Lost Wood Divide</td>
<td>114.27</td>
<td>43.83</td>
<td>2409</td>
</tr>
<tr>
<td>MAM</td>
<td>Magic Mountain</td>
<td>114.30</td>
<td>42.18</td>
<td>2098</td>
</tr>
<tr>
<td>MEL</td>
<td>Meadow Lake</td>
<td>113.32</td>
<td>44.43</td>
<td>2700</td>
</tr>
<tr>
<td>MCS</td>
<td>Mill Creek Summit</td>
<td>114.47</td>
<td>44.47</td>
<td>2683</td>
</tr>
<tr>
<td>MSE</td>
<td>Moonshine</td>
<td>113.42</td>
<td>44.42</td>
<td>2268</td>
</tr>
<tr>
<td>MOC</td>
<td>Moore Creek</td>
<td>113.95</td>
<td>45.67</td>
<td>1890</td>
</tr>
<tr>
<td>MGC</td>
<td>Morgan Creek</td>
<td>114.27</td>
<td>44.85</td>
<td>2317</td>
</tr>
<tr>
<td>OXF</td>
<td>Oxford Spring</td>
<td>112.13</td>
<td>42.27</td>
<td>2055</td>
</tr>
<tr>
<td>SHM</td>
<td>Sheep Mountain</td>
<td>111.68</td>
<td>43.22</td>
<td>2003</td>
</tr>
<tr>
<td>SGC</td>
<td>Slug Creek Divide</td>
<td>111.30</td>
<td>42.57</td>
<td>2203</td>
</tr>
<tr>
<td>SOR</td>
<td>Somsen Ranch</td>
<td>111.37</td>
<td>42.95</td>
<td>2073</td>
</tr>
<tr>
<td>STM</td>
<td>Stickney Mill</td>
<td>114.22</td>
<td>43.87</td>
<td>2265</td>
</tr>
<tr>
<td>SWP</td>
<td>Swede Peak</td>
<td>113.97</td>
<td>43.82</td>
<td>2329</td>
</tr>
<tr>
<td>VIM</td>
<td>Vienna Mine</td>
<td>114.85</td>
<td>43.80</td>
<td>2732</td>
</tr>
<tr>
<td>WHE</td>
<td>White Elephant</td>
<td>111.42</td>
<td>44.53</td>
<td>2351</td>
</tr>
<tr>
<td>WLD</td>
<td>Wildhorse Divide</td>
<td>112.48</td>
<td>42.75</td>
<td>1979</td>
</tr>
</tbody>
</table>

Harmonic phase value, $t_k$, of the net kth harmonic amplitude, $A_k$, is written as:

$$t_k = \left(\frac{P}{360k}\right)\left(180/\Pi\right)\arctan\left(\frac{B_k}{C_k}\right) + \left(\frac{P}{k}\right)$$  \hspace{1cm} (2)

In (2), $\Pi = 3.1415927$ and the net harmonic amplitudes, $A_k$, can be written as a function: $A_k = (B_k^2 + C_k^2)^{1/2}$. A scaling factor, $P/k$, is used to ascertain the correct harmonic phase solution. By summing over all of the $t=\{1,2,3,\ldots,N\}$ observations and the $k=\{1,2,3,\ldots,N/2\}$ harmonics, the least-squares approximations of the harmonic amplitudes, $B_k$ and $C_k$, are computed as:

$$B_k = \frac{2}{N} \sum \left[y_t \sin\left(360kN/P\right)\right]$$  \hspace{1cm} (3)

and

$$C_k = \frac{2}{N} \sum \left[y_t \cos\left(360kN/P\right)\right]$$  \hspace{1cm} (4)

For this study, $N=12$ observations corresponding to the 12 mean monthly data values. The monthly normals are divided into equal periods of 30.44 days. The period of the observations is 1 year or $P=12$ months. Each of the $y_t$ correspond to the $t=\{1,2,3,\ldots,12\}$ mean monthly precipitation amounts, in units of inches per month. The net harmonic amplitude, $A_k$, is converted to a percent with the magnitudes corresponding to the harmonic strengths. There are a total of $k=N/2=6$ harmonic amplitudes and phase values. The $k$th harmonic curve features a $k$th maximum (or frequency) every $N/k=12/k$ months.
An example of a time series curve for Arco 3 SW, depicting the first three harmonics, which account for 70% of the variability in the time series, is shown in Fig. 3. The dotted curve (labeled "Basic") denotes the mean monthly precipitation time series (inches per month) while the solid curves represent associated harmonics (labeled "Harmonic") indicated by the respective harmonic number, Hk. The first harmonic (H1) clearly shows a tendency for a wet first-half with a drier second-half of the year. The late spring and winter maxima are reflected in the second harmonic curve (H2). Precipitation maxima in January, May, and September are resolved by the third harmonic time series curve (H3).

4. Precipitation Data Analysis

a. The mean monthly precipitation and standard deviation charts

The mean monthly precipitation amounts (Fig. 4) are primarily governed by two variables: elevation and exposure. Elevated locations typically record higher precipitation amounts versus valleys; the complementary effect of elevation and exposure (e.g., orographic up slope) only adds further to the precipitation amounts in the mountains. Figure 4 shows the relatively low precipitation amounts (below 1.0 inch per month) in the USRP and LSRP. While prevailing synoptic mid-level westerly flow occurs over eastern Idaho, the downsloping surface northeast flow around the summertime Great Basin High induces subsidence, attributing in part to the low valley amounts (Trewartha 1981). Late fall and wintertime Pacific cyclogenesis over the northwest United States is a key factor in generating relatively higher precipitation amounts over the mountainous regions of eastern Idaho. For example, in the Upper Snake Highlands, 1.0 to 2.5 inches per month of precipitation occur from orographic enhancement during the wet winter months (Kendrew 1922). Similarly, in the South Central Highlands and Caribou Highlands, precipitation amounts average 1.0 to 3.0 inches per month, (locally 4.0 inches per month) as moist west to northwest flow is forced up the east to southeast facing terrain inducing upslope precipitation (Trewartha 1981). Figure 5
Fig. 6. First harmonic amplitude (percent)

Fig. 7. First harmonic phase (months)

displays the standard deviation for the mean monthly precipitation normals. The higher deviations are generally situated in regions of elevated topography (Fig. 1) where there is greater variability in the seasonal precipitation patterns.

b. The first harmonic amplitude percentage and phase charts

The first harmonic amplitude (as a percent) and phase (month of the first harmonic in calendar months) charts represented in Figs. 6 and 7, illustrate the tendency for one maximum and one minimum in the time series data. Dashed contours highlight the beginning months of the four seasons in Fig. 7. Relative to the other harmonics, large first harmonic percentages suggest a strong annual tendency for precipitation in the time series. A large area of strong (60% to 80%) winter maxima covers the Eastern Magic Valley (e.g., Richfield). High first harmonic percentages are also evident in the highlands: Central Mountains (e.g., Stanley (STN)), South Central Highlands (e.g., Howel Canyon (HOC)), near Wildhorse Divide (WLD), east of Oxford Spring (OXF), and in the Upper Snake Highlands near White Elephant (WHE)). In addition, contributions from the first harmonic are large (40 to 60%) over the southern part of the LSRP with maxima during February and March (Fig. 7). The cold season maxima are correlated with winter cyclogenesis associated with the vigorous Aleutian Low and the southward descent of the North Pacific Polar Jet into the Great Basin. (Trewartha 1981) . When the eastern Pacific High shifts northward and eastward from early July through August, the SRP experiences increasing subsidence and anticyclonic controls accounting for the dry, late summer period (Trewartha 1981). The time series for Richfield and White Elephant (Figs. 8 and 9, respectively) indicate precipitation maxima from November through January. In these plots, the dotted curve (labeled “Basic”) denotes the mean monthly precipitation time series (inches per month) while the solid curves represent associated harmonics (labeled “Harmonic”) indicated by the respective harmonic number, Hk. A phase transition from winter to spring to summer maxima occurs across the Central Mountains from Stanley (STN) to Challis (CHA) (Figs. 10 and 11). While both stations show ~55% percent contributions from the first harmonic, a June (t=6) maximum occurs at Challis, while a December (t=12) maximum is noted at
Winter cyclonic controls are more prevalent in the west Central Mountains where elevation and exposure to Pacific moisture help produce precipitation. Conversely, in the east Central Mountains, the influence from summer convection becomes more pronounced versus winter controls because the west Central Mountains remove much of the moisture from the wintertime synoptic-scale flow. A second transition region in first harmonic phase maxima is also noted from a July \((t=7)\) maximum at May (MAY) to a January \((t=1)\) maximum near Meadow Lake (MEL) as winter cyclonic precipitation becomes more important in the annual cycle versus summer convection. The meridionally oriented first harmonic summer maxima which intrudes from southeast of Howe (HOW) to near Lima (LIM) may signal the northward extent of the summer monsoon, which originates over Arizona and New Mexico during June and July (Trewartha 1981). Contributors to late winter February \((t=2)\) and March \((t=3)\) maxima across the LSRP and USRP include snowfall produced by Pacific low pressure systems and in part by post-cold frontal mesoscale winter convergence zones (Andretta and Hazen 1998). The convergence mechanism is orographically-driven and forms when moist air flowing northwesterly through the Big Lost, Little Lost, and Birch Creek Valleys (Fig. 2) merges with southwesterly flow in the SRP, generating clouds and often bands of light to moderate precipitation from between American Falls 1 SW and Blackfoot 2 SSW to near Pocatello WSO Airport (PIH). The strong first harmonics located from American Falls to Arbon 2 NW (ARB) are influenced by this boundary.

c. The second harmonic amplitude percentage and phase charts

The second harmonic amplitude and phase charts are illustrated in Figs. 12 and 13, respectively. These charts indicate the tendency for two maxima and two minima in the annual march of precipitation. Thus, there is a second maximum in Fig. 13 (not shown) which occurs 6 months from the displayed calendar month maximum on this chart. Noteworthy features include an absolute maximum of \(-70\%\) located near St. Anthony 1 WNW in the second harmonic amplitude percentage map. A dashed 40\% isoline contours the shape of the USRP and LSRP indicating a significant (40 to 70\%) contribution from the second harmonic amplitudes in the precipitation time series. Figure 12 also shows a large area of over 50\% contributions centered near West Yellowstone, Montana (WEY). The phase chart shows May \((t=5)\) and November \((t=11)\) maxima over most of eastern Idaho (e.g., “Snake River” regime; Kendrew 1922). The strong spring and summer maxima are driven by the northward movement of the North Pacific Polar Jet from the Great Basin into western Canada while the late fall and early winter maxima (November and December) are linked to the southward migration of the jet from western Canada into the Great Basin (Trewartha 1981). The movement of the jet into eastern Idaho causes stronger southwest flow allowing greater exposure to terrain-induced precipitation forcing and a more favorable track for frequent rain/snow-producing Pacific cyclones. Evidence of this trend is provided in the time series of two valley stations, Pocatello WSO Airport and Idaho Falls 2.
Fig. 12. Second harmonic amplitude (percent)

Fig. 13. Second harmonic phase (months)

Fig. 14. Precipitation (in.) and harmonic time series for Pocatello WSO AP

Fig. 15. Precipitation (in.) and harmonic time series for Idaho Falls 2 ESE

d. The third harmonic amplitude percentage and phase charts

The third harmonic amplitude percentage map, Fig. 18, illustrates the importance of three maxima and three minima in the annual march of precipitation. The associated phase map is illustrated in Fig. 19, displaying the calendar month of the third harmonic maximum. (The other two maxima (not shown) occur 4 months before and after this value.) Third harmonic amplitudes are generally small (<20%) across most of eastern Idaho. However, a small area of 20 to 30% contributions covers most of the Caribou Highlands in Fig. 18. A second region of 30 to
40% contributions extends from Tetonia Experimental Station (TET) to Driggs (DRG); a local maximum of 40% is located near Palisades (PAL). Figure 19 indicates a general pattern of third harmonic maxima in January (t=1), May (t=5), and September (t=9) across most of eastern Idaho. (In the Magic Valley, third harmonic maxima occur from April (t=4) to July (t=7) but percentage contributions are less than 10%.) The area located from the Teton Range into the Caribou Highlands is less influenced by warm/cold season maxima related to Pacific cyclonic controls and Polar Jet transitions and to a much greater degree is influenced by large-scale orographic precipitation induced by westerly up slope of moist air along the east to southeast facing slopes of the Caribou Highlands. Thus, Fig. 18 indicates a west to east gradient from Idaho Falls 2 ESE (10%) to Palisades (40%) in the third harmonic amplitude data, suggesting another gradation in climate regimes, with a tendency for higher frequency seasonal precipitation events from the eastern part of the USRP to near the Teton Range (along the Idaho-Wyoming border) and extending into the Caribou Highlands. The time series for Palisades (Fig. 20) illustrates the strong tendency for three maxima and minima in the annual precipitation time series. The second (H2)
Fig. 20. Precipitation (in.) and harmonic time series for Palisades and third (H3) harmonic curves reinforce each other during March (minimum) and May (maximum).

e. The higher harmonic amplitude percentage and phase charts

The fourth harmonic amplitude map (Fig. 21) indicates an area of 20 to 30% contributions from the fourth harmonic situated south of the Central Mountains with an absolute maximum of 32% near Arco 3 SW. The locally higher magnitudes near Howe and Arco 3 SW appear to be associated with their geographical locations at the terminations of the Big and Little Lost River Valleys, respectively (Fig. 1). The fourth harmonic phase chart (Fig. 22) displays the tendency for four maxima and four minima in the annual march of precipitation; it shows February (t=2), May (t=5), August (t=8), and November (t=11) maxima in these areas. Both Howe and Arco 3 SW may be influenced by both small-scale upslope and convergence due to the slight elevation in topography relative to the surrounding terrain and flow interaction between the SRP and central valleys. Bjorem (1969) noted that these varying wind flow patterns aid in the formation of squall line thunderstorms near Arco 3 SW during the spring and summer months.

The percentage contributions from fifth harmonic amplitudes are relatively small in eastern Idaho (not shown) and approach about 10% near Oakley (OAK); phase maxima occur in May. Contributions from the sixth harmonic amplitude and phase charts (not shown) are less than 5% across east Idaho indicating that salient bi-monthly changes in the annual precipitation march, even over complex terrain, are very small.

5. Conclusions

The method of harmonic analysis was used to illustrate the intensity and phase of precipitation regimes in eastern Idaho using NCDC 30-year normals for 67 climate stations and 33 NRCS SNOTEL stations in eastern Idaho, including the conterminous regions of Montana, Utah, and Wyoming. Cold season precipitation maxima, as expressed by the first harmonic amplitudes, are evident in the Magic Valley, west Central Mountains, and Upper Snake Highlands. These maxima are highly correlated with Pacific cyclogenesis while summer minima are associated with the subsident influences of the Great Basin High (Trewartha 1981). The eastern part of the
Central Mountains exhibits strong summer maxima where terrain blocking inhibits winter precipitation, and warm season convection is more dominant versus cold season Pacific cyclonic controls. Phase transition regions in the first harmonic are evident from a January maximum at Stanley to a July maximum at May to a January maximum at Meadow Lake.

The meridionally oriented first harmonic summer maxima which intrudes from east of Howe to near Lima may reflect the northward extent of the summer monsoon, which originates over Arizona and New Mexico during June and July (Trewartha 1981). Moreover, salient first harmonics over the Upper Snake River Plain transition to well-defined second harmonics over the Upper Snake Plain, with an absolute second harmonic maximum near St. Anthony 1 WNW. The spring and fall maxima are influenced by the seasonal transitions of the North Pacific Polar Jet (Trewartha 1981). An area of strong third harmonics, situated from the eastern part of the Upper Snake River Plain to near the Idaho-Wyoming border and into the Caribou Highlands, appears to be associated with large-scale orographic precipitation forcing. This may be linked to westerly upslope of moist air along the windward sides of the Teton Range in western Wyoming. Finally, strong fourth harmonic amplitudes are observed near Howe and Arco 3 SW, possibly due to local upslope and convergence forced by terrain elevation differences and interaction of wind flow in the SRP with the Central Mountain Valleys. However, additional research is still needed to ascertain the precipitation mechanisms which produce the salient third and fourth harmonics in regions of varied terrain.

Acknowledgments

The author would like to thank NCDC and NRCS for providing the mean monthly precipitation normals. A special thanks to Jay Albrecht, Dr. Greg Johnson, Mark Mollner, Dean Hazen, and Rusty Billingsley for providing constructive comments on this paper.

Author

Thomas Andretta serves as lead forecaster at the NOAA/National Weather Service (NWS) Office at Pocatello/Idaho Falls, Idaho. He joined the NWS in May 1993 as a meteorologist intern at the NWS Office in Lake Charles, Louisiana and was promoted to journeyman forecaster at the NWS Office in Pocatello/Idaho Falls in April 1995. He graduated from the State University of New York at Stony Brook in 1988 with a B.S. in Atmospheric Science and in 1991 with a M.S. in Atmospheric Science. He wrote his Master’s Thesis on precipitation perturbations in two versions of the Oregon State University Global Circulation Climate Model which featured variable ambient CO2 concentrations. His area of expertise is in mesoscale meteorology and precipitation climatology. He has authored a recent manuscript in the June 1998 issue of Weather and Forecasting analyzing a boundary layer convergence zone event in the Snake River Plain of eastern Idaho.

References


