A Polar Area Index Methodology for Forecasting Hemispheric Surface Temperature Trends

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Introduction

Angell and Korshover (1977A,B; 1978A,B,C) published a series of papers on expansion and contraction of the arctic air pool about the polar vortex after calculating the area enclosed within a specified isopleth on a seasonal 300 mb chart. Mean seasonal values denoting expansion and contraction were presented. The magnitude of the area enclosed within the contour was shown to be an effective reflection of the Northern Hemispheric surface temperature.

To be operationally significant and useful, an area index representative of the cool air reservoir and its seasonal expansion or contraction needs to be computed far more frequently than once each season. The chart used would have to be routinely available to the forecaster. Peterlin (1981) developed a circumpolar area index using the 5640 meter isoheight line on the 500mb Northern Hemispheric analysis. This constant pressure surface depiction is produced by the National Weather Service in a fully automated procedure at 000Z and 1200Z daily. The polar stereographic projection is on a scale of 1 to 40 million on which geopotential height intervals are drawn with a spacing of 60 meters (Figure 1).

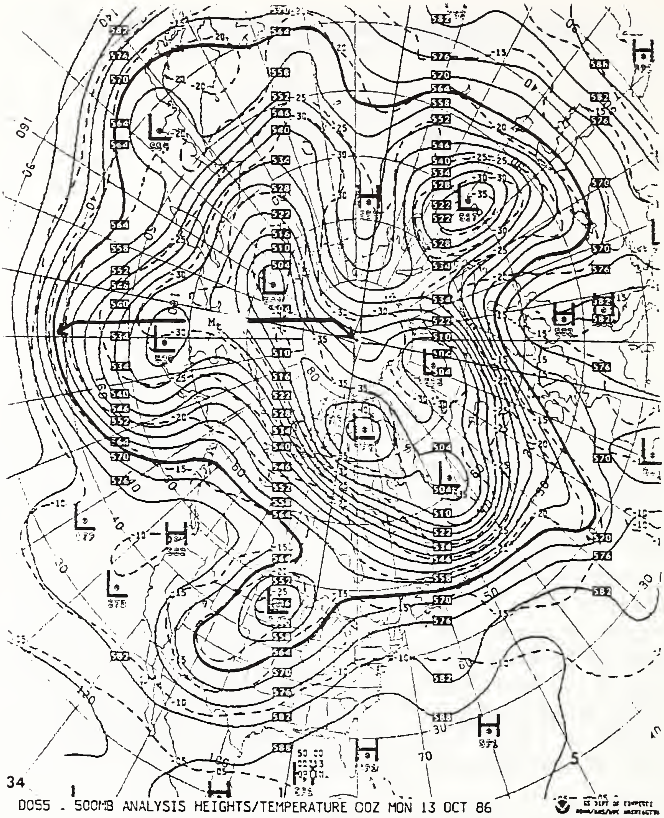
The objective of this paper is to demonstrate some techniques and procedures to regionalize and geographically define a surface hemispheric temperature forecast.

Data, Procedures, and Results

Index values were computed on fixed dates at weekly intervals by measuring the length of the axis from the pole to the 5640-meter isoheight line along each 10° longitude as illustrated in Figure 1. Fixed dates were chosen to correspond with the beginning of each climatological week except that the week beginning January 3 is numbered 1 rather than the week beginning March 1.

Because of map size distortion, index values are adjusted to an adopted 1972 standard based on a comparison of the length of the 60°W meridian from 20°N to 30°N latitude. The index value for each date is simply the summation of the 36 meridional lengths from the pole to the 5640-meter isoheight line. These index values represent the area enclosed within the 5640-meter isoheight line.

A plot of these indices by week displays a sinusoidal tendency. An example for one sample year (1972) is shown in Figure 2. Index values reach a minimum in summer (week 30 in 1972) and a maximum in the winter (week 6 in 1972). With ten years of weekly index calculations (1972-1981), weekly means were calculated as "normal" to allow synoptic comparison (Table 2). By measuring current vortex size each week and comparing it to its normal, the relative size of the cool air pool and its anomaly within the annual cycle of change can be quantified.



$$A_i = \sum_{t=1}^{36} M_t$$

FIGURE 1. 500mb analysis with indexing technique highlighted. 5640-meter contour darkened.

TABLE 1. Fixed dates on which index values were computed.

week	date	week	date	week	date	week	date
1	Jan 3	14	Apr 5	27	Jul 5	40	Oct 4
2	Jan 10	15	Apr 12	28	Jul 12	41	Oct 11
3	Jan 17	16	Apr 19	29	Jul 19	42	Oct 18
4	Jan 24	17	Apr 26	30	Jul 26	43	Oct 25
5	Jan 31	18	May 3	31	Aug 2	44	Nov 1
6	Feb 7	19	May 10	32	Aug 9	45	Nov 8
7	Feb 14	20	May 17	33	Aug 16	46	Nov 15
8	Feb 21	21	May 24	34	Aug 23	47	Nov 22
9	Mar 1	22	May 31	35	Aug 30	48	Nov 29
10	Mar 8	23	Jun 7	36	Sep 6	49	Dec 6
11	Mar 15	24	Jun 14	37	Sep 13	50	Dec 13
12	Mar 22	25	Jun 21	38	Sep 20	51	Dec 20
13	Mar 29	26	Jun 28	39	Sep 27	52	Dec 27

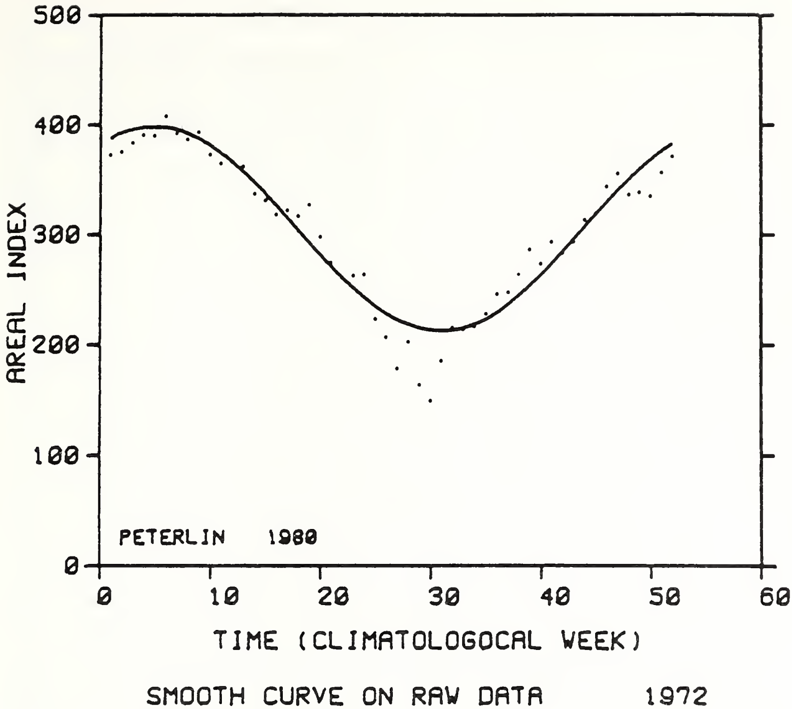


FIGURE 2. 1972 raw data plot superimposed upon first harmonic fit.

The weekly indices for each year were smoothed by fitting the first harmonic on time (week).

$$Y_t = a_0 + A \cos (ct - \Theta)$$

where Y_t is the index value for week t (t = 0, 1, 2. . .5); a_0 is the average of the 52 indices (Y); A is the amplitude or half the range from the maximum to minimum Y. The constant $C = 2\pi/52$ converts the numbered weeks to angular measure in radians and Θ is the phase angle or time of the maximum Y. To estimate the constants from the observed Y_t value, the equation was rewritten:

$$Y_t = a_0 + a_1 \cos(ct) + b_1 \sin(ct)$$

where $A = \sqrt{a_1^2 + b_1^2}$ and $\tan \Theta = b_1/a_1$. The coefficients a_0, a_1, and a_2 were estimated by the method of least squares. Smoothed 1972 data is superimposed on the 1972 raw data plots in Figure 2. Ten year means (normals) were also fit and are used as the basis for comparison in Figure 3. The area plot is essentially bimodal. Yearly subsets are either expansional or contractional rather than being defined by the more traditional seasons. The contractional regime begins about week 7 (February 14) and ends about week 29 (July 19). The expansional regime begins week 29 (July 19) and continues to week 7 (February 14).

First harmonic smoothing offers forecast potential through the use of persistence. Persistence is still one of the most useful forecasting tools available to the operational

TABLE 2. Raw index values and 10 year mean as "NORMAL".

Week	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	NRML
1	376	356	373	359	365	383	377	375	391	377	372
2	378	406	400	381	354	389	382	369	395	370	381
3	387	400	384	376	368	399	394	383	387	373	383
4	394	370	371	379	375	396	384	387	387	384	383
5	396	352	394	375	382	390	396	394	391	376	383
6	411	375	375	398	384	384	398	382	388	375	386
7	396	381	387	396	379	369	402	371	397	377	387
8	390	370	360	384	380	369	381	380	397	377	380
9	396	382	360	382	373	368	400	384	376	391	380
10	376	372	377	389	383	345	383	368	379	361	372
11	368	368	375	373	377	357	365	369	362	377	369
12	369	362	348	379	368	353	367	364	372	379	367
13	365	363	375	367	349	352	355	353	357	364	359
14	339	363	357	352	352	339	354	350	348	327	349
15	334	381	352	338	348	327	349	347	340	339	344
16	321	355	340	327	331	323	354	334	324	320	334
17	325	348	334	312	328	324	348	307	318	324	327
18	320	325	340	309	325	305	311	320	323	301	317
19	330	301	317	302	303	305	297	301	318	297	307
20	301	301	305	295	291	293	294	281	285	288	293
21	278	286	310	277	283	283	301	283	283	376	287
22	264	299	302	275	287	258	276	255	278	277	276
23	266	255	280	287	250	262	262	255	244	277	266
24	267	260	240	257	267	232	253	247	240	261	253
25	227	222	234	233	238	237	246	232	233	222	235
26	211	222	244	184	174	241	215	219	216	206	216
27	182	215	223	176	233	184	218	180	230	202	208
28	207	217	199	192	213	159	180	216	219	208	200
29	164	203	213	157	217	204	210	191	211	190	189
30	152	205	171	206	217	209	212	193	194	191	193
31	189	218	185	190	192	176	202	200	198	183	197
32	219	184	200	194	189	217	222	228	192	161	203
33	217	204	215	232	213	196	241	197	196	190	211
34	220	198	239	239	209	229	222	226	198	202	216
35	231	239	232	238	244	247	248	238	225	205	233
36	249	252	261	237	241	238	275	231	253	231	246
37	250	235	246	247	244	235	257	270	251	254	250
38	267	280	260	251	258	254	255	258	265	280	263
39	289	271	276	269	288	268	275	267	283	270	275
40	276	252	267	279	295	273	283	290	293	280	280
41	296	290	287	287	301	295	275	292	281	301	288
42	286	301	295	306	305	303	299	283	311	289	296
43	297	300	291	305	334	299	298	306	315	289	302
44	316	325	326	312	318	309	296	325	318	306	315
45	322	322	321	321	322	312	299	311	339	305	320
46	346	331	322	335	341	316	328	317	330	331	333
47	358	336	341	340	348	355	330	315	338	344	341
48	339	341	358	359	347	348	353	334	344	348	347
49	341	357	369	338	359	370	347	326	351	352	350
50	337	359	364	368	359	354	344	360	354	363	357
51	359	368	362	349	388	379	364	378	360	372	366
52	374	359	353	360	403	363	377	372	359	378	371

meteorologist. By fitting the first harmonic to the immediate 17 weeks of actual raw index values, the output, assuming persistence, becomes the forecast product.

The 1982 forecast plot in Figure 3 displays the warm hemispheric winter weeks and the cool but near normal transitional spring season (actual data). The forecast period

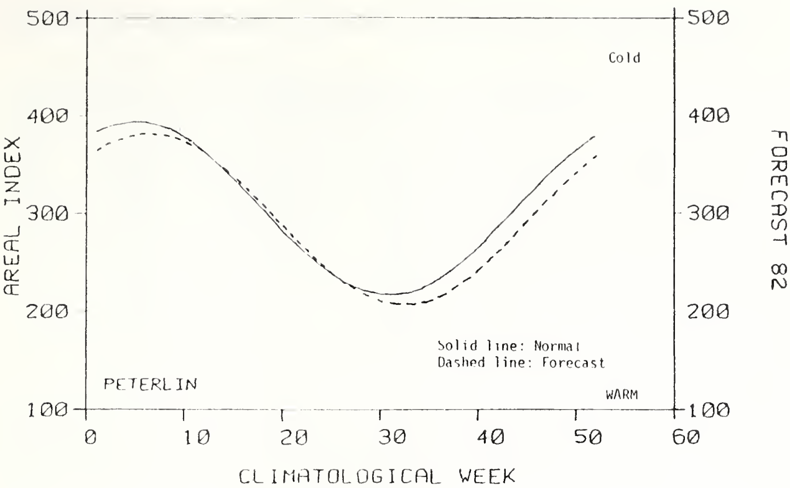


FIGURE 3. First harmonic normal superimposed upon smooth forecast plot.

called for a warmer than normal hemispheric summer with crossover about week 23 (June 7). The warm contracted pattern is maintained through the fall (Figure 3).

The timing of expansional or contractual momentum and trend development of the raw mean data is highlighted by the week to week differences in Table 3. Trend reversal is evident from week 7 (Feb. 4) to 8 (Feb. 21) and week 29 (July 19) to 30 (July 26). Week to week differences can highlight trend definition and acceleration of the differential may be an indication of momentum. Five week mean index values were also computed on traditional seasonal dates. These mean indices are shown in Table 4.

Mean winter index values were greatest in 1972, 1978, and 1980. Mean values 1973 to 1976 were declining or stable with trend reversal in 1976. This pattern is associated with the extreme winter that occurred in much of the continental United States in 1976-77. Index values during the winter years 1977-1978 were larger than values calculated for the years 1973 to 1976.

TABLE 3. Raw normal week to week area index differential.

Weeks	Diff	Weeks	Diff	Weeks	Diff	Weeks	Diff
52 1	+1	13 14	−10	26 27	−8	39 40	+5
1 2	+9	14 15	−5	27 28	−8	40 41	+8
2 3	0	15 16	10	28 29	−11	41 42	+8
3 4	0	16 17	−7	29 30	+4	42 43	+8
4 5	0	17 18	−10	30 31	+4	43 44	+13
5 6	+3	18 19	−10	31 32	+6	44 45	+5
6 7	+1	19 20	−14	32 33	+8	45 46	+13
7 8	−7	20 21	−6	33 34	+5	46 47	+8
8 9	0	21 22	−11	34 35	+17	47 48	+6
9 10	−8	22 23	−10	35 36	+13	48 49	+3
10 11	−3	23 24	−13	36 37	+4	49 50	+7
11 .12	−2	24 25	−18	37 38	+13	50 51	+9
12 13	−8	25 26	−19	38 39	+12	51 52	+5

TABLE 4. Five week mean area index values centered on indicated seasonally definitive date and year.

Year	Jan 31	May 3	Aug 2	Nov 1
1972	396.8	319.4	188.2	313.4
1973	375.6	326.0	202.8	336.0
1974	382.2	327.2	196.8	311.0
1975	384.8	309.0	195.8	315.8
1976	377.6	315.6	205.6	324.0
1977	387.6	310.0	200.4	307.8
1978	394.8	320.8	217.4	304.0
1979	383.4	308.6	201.8	308.4
1980	390.0	313.6	198.2	312.6
1981	377.0	306.0	183.0	315.8

The largest (coolest) summer index values are noted in 1973, 1976 and 1978. Definite trend reversal toward warming began after the 1978 period of peak cooling and persisted to 1981.

Discussion and Further Analysis

The computed index values are useful in determining the relative size of the cool air pool, but the application of these data lacks regional geographic definition throughout the hemisphere. A synoptic study of the 5640-meter contour may provide additional insight into geographic or regional displacement including preferred trough or ridge positioning. To accomplish this, the original 36 individual lengths used in computing the index values were used to reproduce a synoptic climatology of the 5640-meter isoheight line. Ten year mean positions for some typical examples are presented in Figures 4, 5, 6, and 7. Seasonal geographic placement of this isoheight line will eventually be compared to the geographic placement of the polar jet, which is frequently thought of as the driving force within the westerlies for cyclogenesis.

The January 24 depiction in Figure 4 depicts an almost complete expanded pattern. Zonal (west to east) flow is dominant with few small scale oscillations. Azonal (meridional) flow is most apparent along 130°-160° W off the California coast. Some broad troughing is noted along the central Gulf coast. Deep contiguous ridging and troughing is evident from the eastern Iberian Peninsula to the Libyan desert.

The April 26 depiction in Figure 5 displays cross latitudinal flow in the United States, the central Atlantic, and over the Asian land mass. Area balance about the vortex is not as evident as in mid winter. Some accelerated contraction is noticeable on the North American and Asian land masses. Flow is much less zonal with multiple trough/ridge positioning from the water off the California coast to the southeastern seaboard and over the Aral Sea. Broad troughing is noted off the Southeastern Seaboard of the United States, across northern Africa, and over the islands of Japan.

The July 26 depiction in Figure 6 is shortly after the contractual minimum. The contour plot is asymmetric with elongation over the Atlantic and northern Pacific and contraction over the land masses. Troughing is evident over the cooler waters of the North Atlantic and eastern Pacific. Flow is typically azonal with multiple minor waves.

The October 25th map in Figure 7 displays a more balanced area depiction. Flow is more zonal again. Cross latitudinal flow is noted over the Pacific northwestern section of the United States. Elsewhere, there is little troughing.

A week to week wave count was completed (Table 5). The number of waves is at a minimum during the expansionary winter period and slowly builds to a maximum dur-

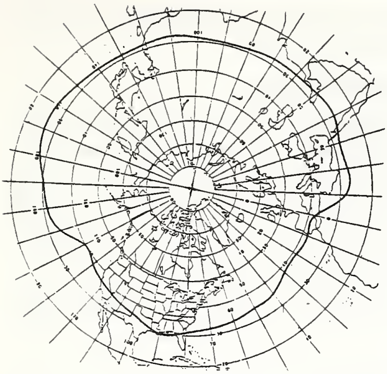


FIGURE 4. 5640-meter contour plot. 10 year mean. January 24 (week 4).

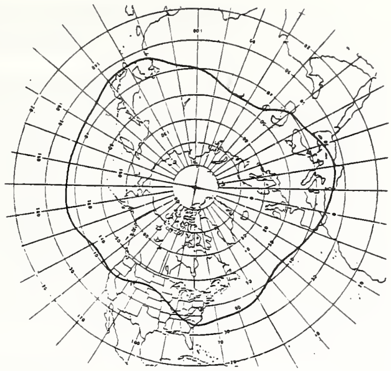


FIGURE 5. 5640-meter contour plot. 10 year mean. April 26 (week 17).

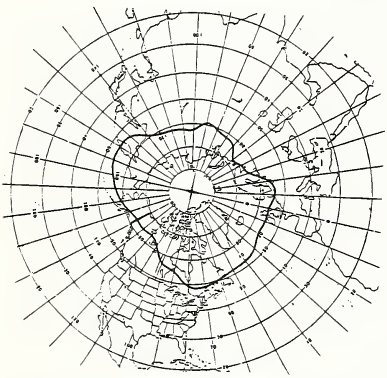


FIGURE 6. 5640-meter contour plot. 10 year mean. July 26 (week 30).

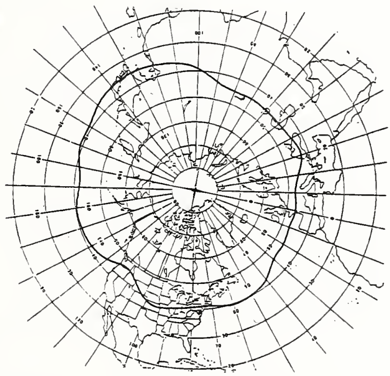


FIGURE 7. 5640-meter contour plot. 10 year mean. October 25 (week 43).

TABLE 5. Weeky Wave Count.

Week	Count	Week	Count	Week	Count	Week	Count
1	4	14	7	27	11	40	7
2	3	15	6	28	11	41	6
3	3	16	7	29	9	42	4
4	3	17	6	30	7	43	5
5	3	18	4	31	8	44	5
6	3	19	6	32	6	45	6
7	2	20	6	33	6	46	5
8	5	21	7	34	7	47	6
9	4	22	8	35	7	48	6
10	5	23	5	36	7	49	5
11	5	24	6	37	8	50	3
12	4	25	8	38	6	51	5
13	7	26	7	39	7	52	6

ing the traditional summer. This suggests that wave number can be used in developing additional information related to season temperature trends.

Conclusion and Recommendations

The area index developed appears to be representative of hemispheric seasonal trends in surface temperature. Seasonal timing differential and statistical manipulation of normalized index values can offer additional corroborative evidence about these trends. The synoptic study of the 5640-meter contour appears to be a promising source to identify preferred troughing and ridging positioning which may provide the regionalization necessary to link the hemispheric area index to surface temperature forecasts. Much remains to be done, and an actual hemispheric temperature data base is being sought to relate these seasonal circumpolar area index patterns to seasonal trends in surface temperature.

Acknowledgment

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