CENTRAL/SOUTHERN CALIFORNIA CLOSED LOWS DURING MARCH AND APRIL

A climate study for Northern Arizona

by

Darren McCollum

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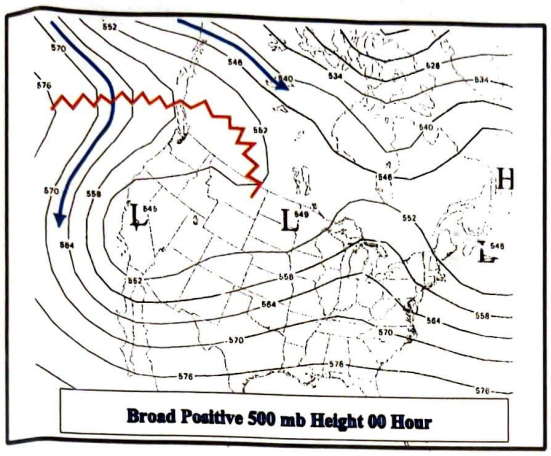
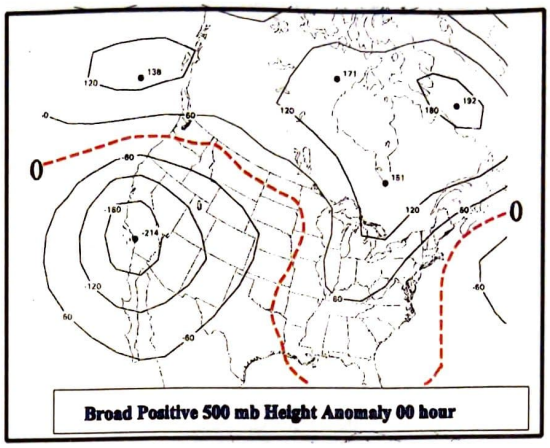
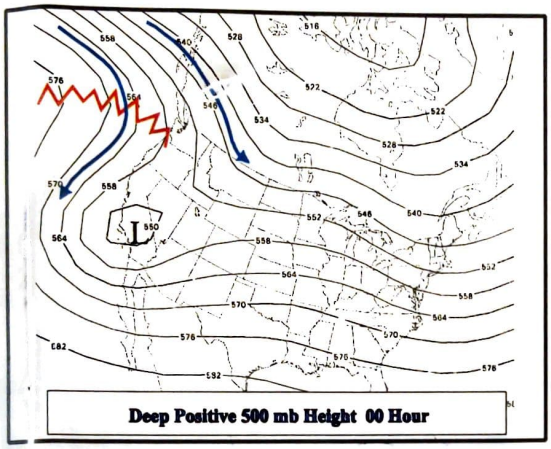
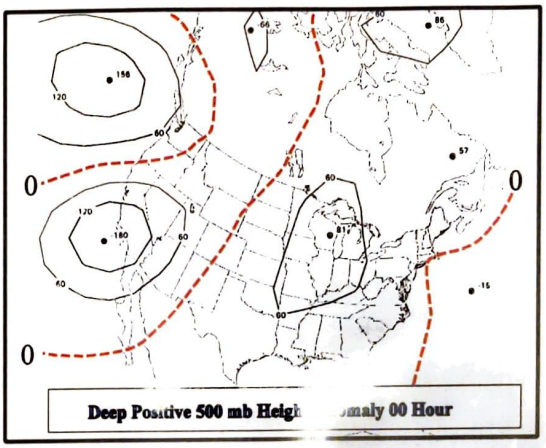
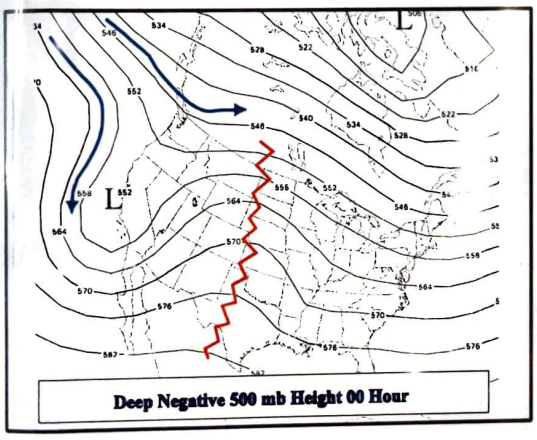
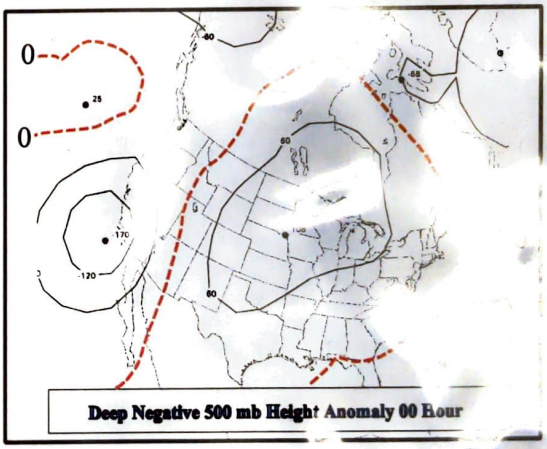


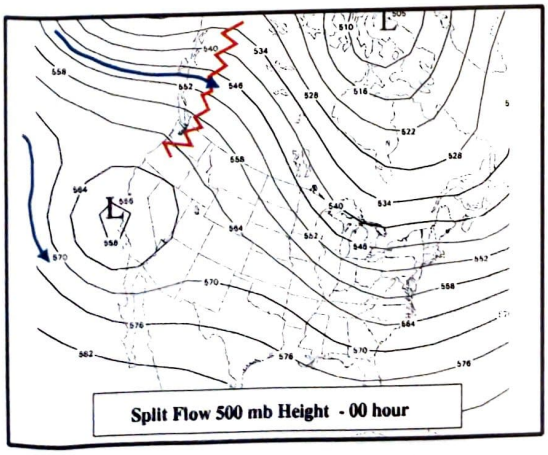


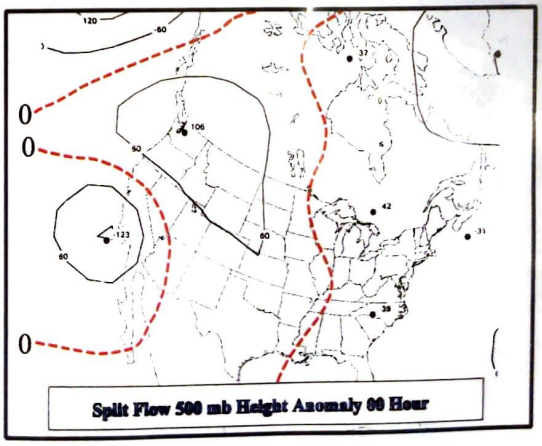












Reason for Study

Accurate winter forecasting is important for public safety. This study investigates the climatological characteristics of closed-low pressure systems ("closed-lows") that move over central and southern portions of California during the months of March and April. Closed lows that move across California typically result in precipitation events across northern Arizona with snow being likely above the 6000 foot level. By understanding the climatological aspects of these systems the impacts on northern Arizona can be better anticipated.

Description of Analysis process and Data

The years 1975 through 1994 for the months of March and April were used as the time period for this study. During this period all 500-mb closed-lows that developed over the central and southern portions of California were included for study. In addition, any 500-mb closed-lows that developed within 100 miles of the central and southern California coast were included. If a storm started in February and lasted into March or started in April and lasted into May it was included in the data set. Using this process, 40 cases were selected for the data set.

The National Meteorological Center (NMC, now NCEP) CD-ROM of the gridded final analysis fields was used for the study. The historical daily precipitation data for Flagstaff was used to identify precipitation amounts and days of occurrence. Once all the California closed-lows were identified the 500 mb charts were subjectively analyzed to identify similarities. Four recurrent pattern types were identified: 1) Broad Positive Tilt Trough, 2) Deep Positive Tilt Trough, 3) Deep Negative Tilt Trough and 4) Split Flow Trough Pattern. (These will be described later). Using the precipitation data at Flagstaff it was observed that, except for the Broad Positive pattern, there were important climatological differences between closed-low storms that result in the early onset of precipitation (called **PRE** for pre-frontal or well in advance of the storm center) and late onset of precipitation (called **POST** for post-frontal). Precipitation with the POST type system typically is associated with the passage of the cold core.

Description of Symbols, Terms, Charts and Tables

Throughout the following pages various descriptive terms and symbols are used. The following lists the definitions for the more important terms and symbols:

TERMS:

PRE - These stronger storms tend to form precipitation in advance of the cold front. On a larger scale, PRE type storms tend to form precipitation at Flagstaff before the 500 mb closed-low forms over central and southern portions of California.

POST - These weaker storms tend to form precipitation later as the mid-level cold core moves into Arizona.

-24 HOUR - These charts show the pattern characteristics 24-hours before a closed-low develops over central and southern portions of California.

00 HOUR - These charts show the pattern characteristics once the 500 mb closed-low has formed over central and southern portions of California.

WIND - The wind speed contours are lableled in knots with the arrows respresenting the actual wind vectors. Charts are shown for the 250 and 500 mb levels.

HEIGHT - Height charts are for the 500 mb level and are shown in decameters.

DIFFERENCE - The difference fields are for the 500 mb height field and are shown in +/- meters.

TEMPERATURE - The temperature fields are shown for the 500 mb level with contours every 5 degrees Celsius.

SYMBOLS:

Indicates position of the most important ridge axis (500 mb charts).

Indicates the location of the split in flow (500 mb charts).

Indicates important jet max features that should be closely analyze charts).

Indicates where the gradient in wind speed should be closely analy charts).

Denotes the -20 degree Celsius isotherm (temperature charts).

Denotes the zero meter difference between the pattern type an e long t average (difference charts).

TABLES:

Tables are used to show the timing and other characteristics of precipitation for Flagstaff with each pattern. A description of the Table follows:

The left-most column labeled Before, DAY 1, DAY 2 etc., shows the midnight to midnight time

period relative to when a closed-low formed over the central and southern portions of California. The label "DAY 1" denotes the midnight-to-midnight day the closed-low formed over California. The label "Before" is the day before and the label "DAY 2" is the day after the closed-low first formed over California. If there is no label then no precipitation occurred. The next column "Avg" indicates the average liquid precipitation in inches for the events that resulted in precipitation. The next column "Range" indicates the range of precipitation in inches received from each event. The last column "POP" indicates the percentage of events that resulted in precipitation at Flagstaff. For the pattern types with both PRE and POST characteristics a table is shown for each.

Example Table:

	Avg	Range	POP
Before	0.32	.01-.77	100%
Day 1	0.25	.01-.52	100%
Day 2	0.32	.01-.69	100%
Day 3	0.01	T-.01	25%

1) GENERAL PATTERN TYPES

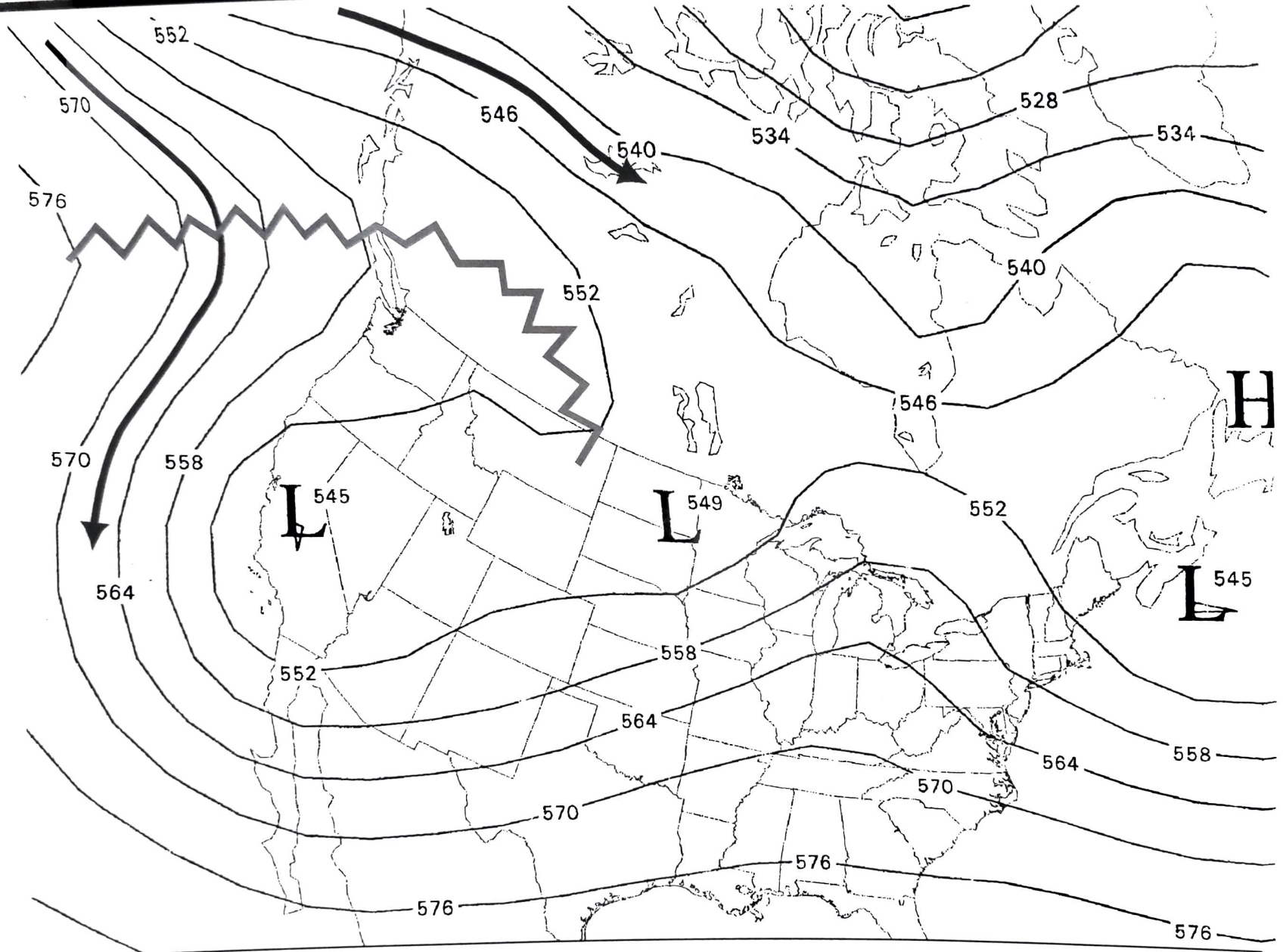
Four pattern types were identified from the 40 cases studied. These were the Broad Positive Tilt Trough (Broad Positive), Deep Positive Tilt Trough (Deep Positive), Deep Negative Tilt Trough (Deep Negative) and Split Flow Trough (Split Flow). A brief description of each pattern type is given below. The charts that follow show the 500 mb height field in decameters (dam) and the 500 mb height anomaly field in meters (m) for each pattern.

Broad Positive - This pattern is characterized by a broad, stationary trough extending over the Great Basin and across the southwest United States. This is the coldest of the pattern types identified with a central height of 545 dam at the 00 hour. There is a distinct and broad negative height anomaly of -214 m centered over the Southern California coast with a positive height anomaly ranging from 120-180 m across Canada..

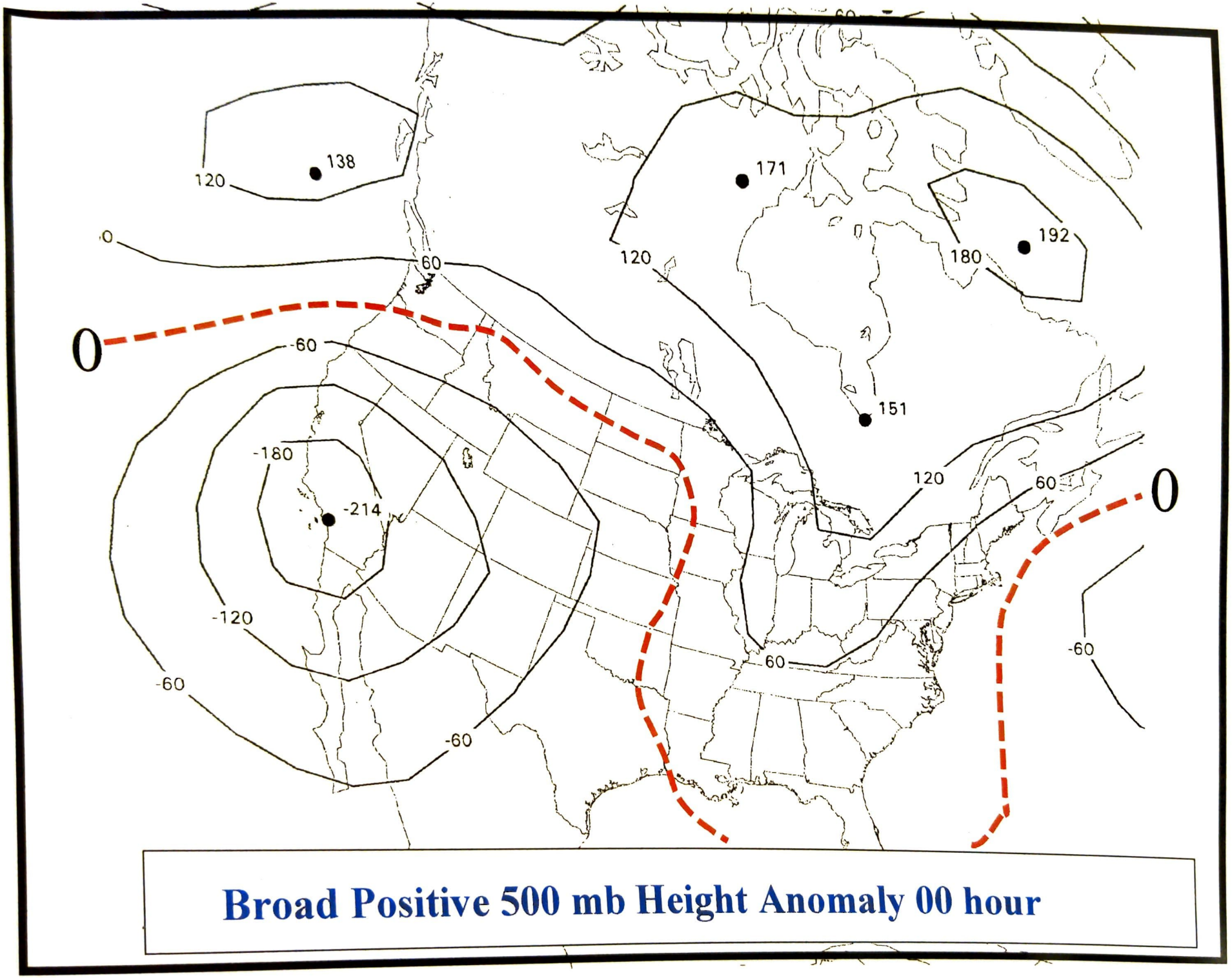
Deep Positive - This pattern is characterized by a positive tilt, shorter wavelength trough that dives southward along the west coast of the United States with the help of strong short wave ridging behind the system to the northwest. A split in the flow is located off the coast of Washington with an east/west ridge axis extending from over the Eastern Pacific into Oregon. The upstream ridge is of a similar wavelength and amplitude to the trough. The downstream ridge is a much longer wavelength and low amplitude. The mean central 500 mb height of this pattern over California is 550 dam. A significant negative height anomaly of -180 m is located off the Southern California coast with a positive height anomaly of 156 meters associated with the high amplitude ridge to the northwest. This pattern exhibits a PRE and POST character with the PRE type tending to occur when the central 500 mb height over California is 550 dam or lower.

Deep Negative - This pattern is characterized by a negative tilt trough that dives southward along the west coast in a manner similar to the Deep Positive pattern. The main difference is that the upstream ridge has a much lower amplitude and it is the downstream ridge that is more important. The wavelength and amplitude of the downstream ridge in the negative tilt case is similar to that of the developing trough. Once over California the mean central height of this pattern is 552 dam. The main height anomalies are associated with the low center (-170 m along the Southern California coast) and the ridge over the central United States (108 m centered over Nebraska and Iowa). This pattern exhibits a PRE and POST character with the PRE type tending to occur when the central 500 mb height over California is 550 dam or lower.

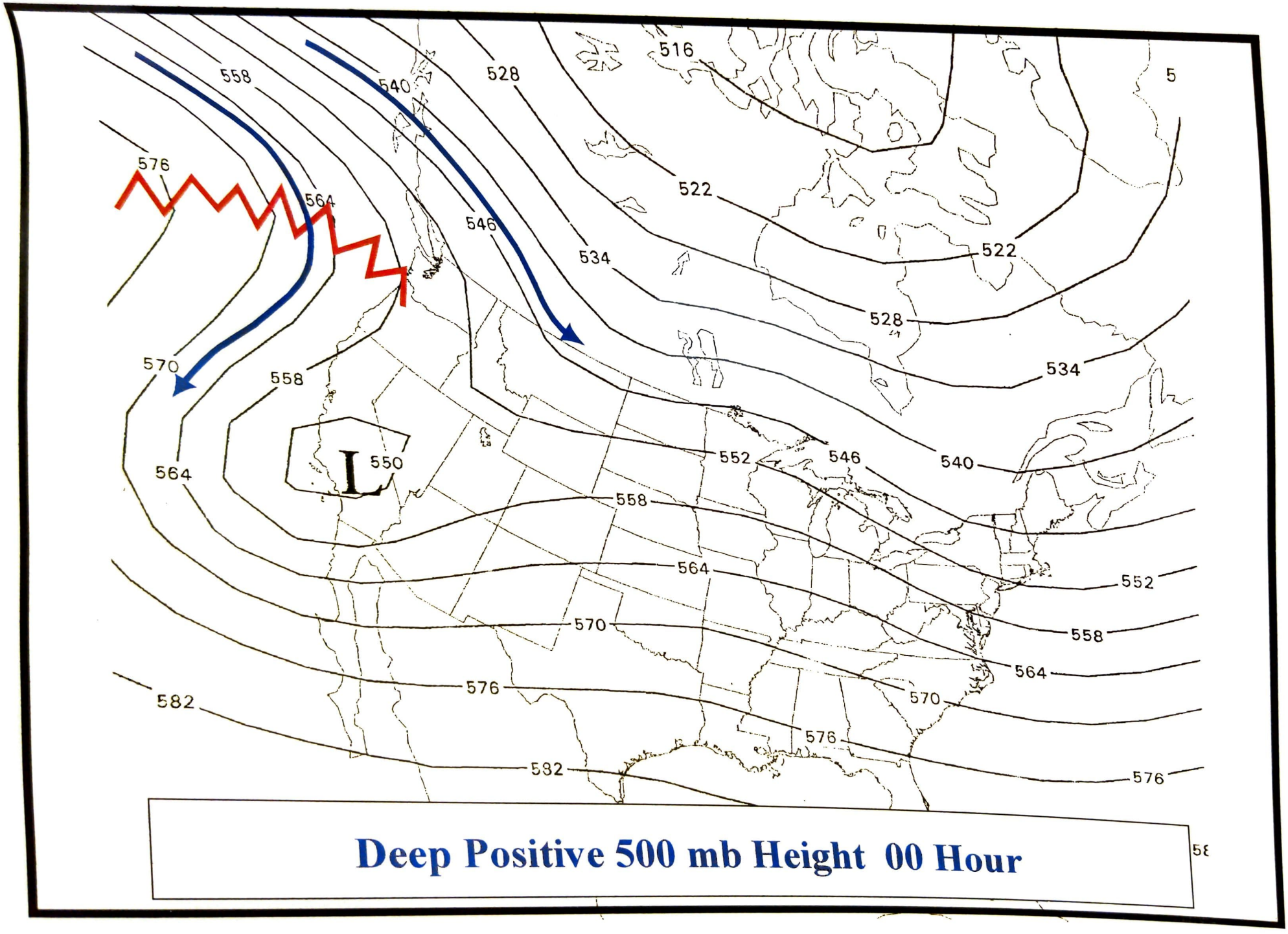
Split Flow - The Split Flow pattern is characterized by a split in the westerlies well off the west coast of the United States with a well defined southern and northern jet branch developing as the system matures. With a low center to the south and high center to the north this pattern takes on a "Rex Blocking" pattern appearance. This is the warmest of the types with a mean central height of 556 mb and it is associated with the second lowest precipitation production. There is a negative height anomaly of -123 off the southern California coast with a positive anomaly of 106 meters over Washington which highlight the "high-over-low" structure. This pattern exhibits a PRE and POST character with the central height having no correlation with the early or late onset of precipitation.



Broad Positive 500 mb Height 00 Hour



Broad Positive 500 mb Height Anomaly 00 hour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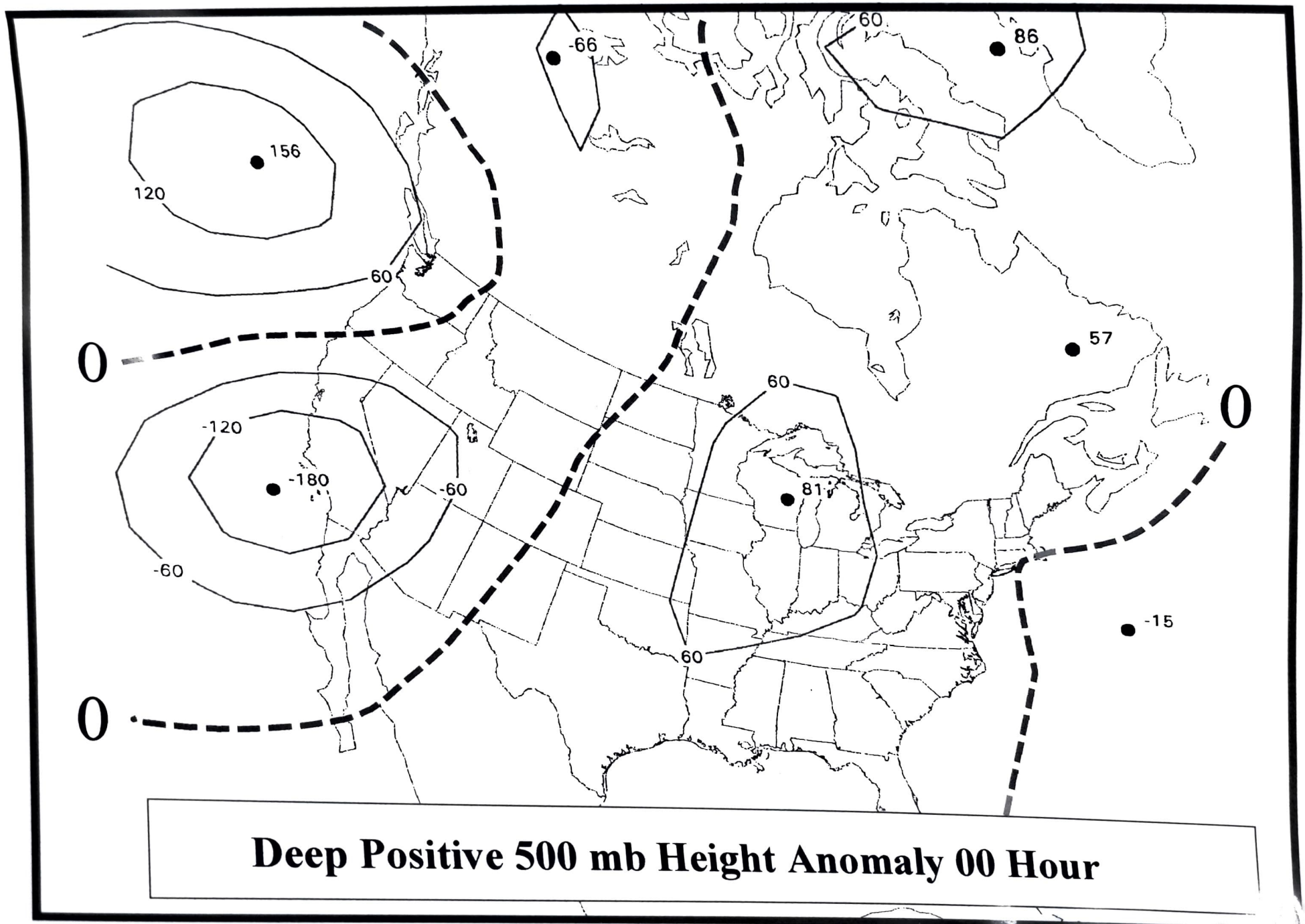
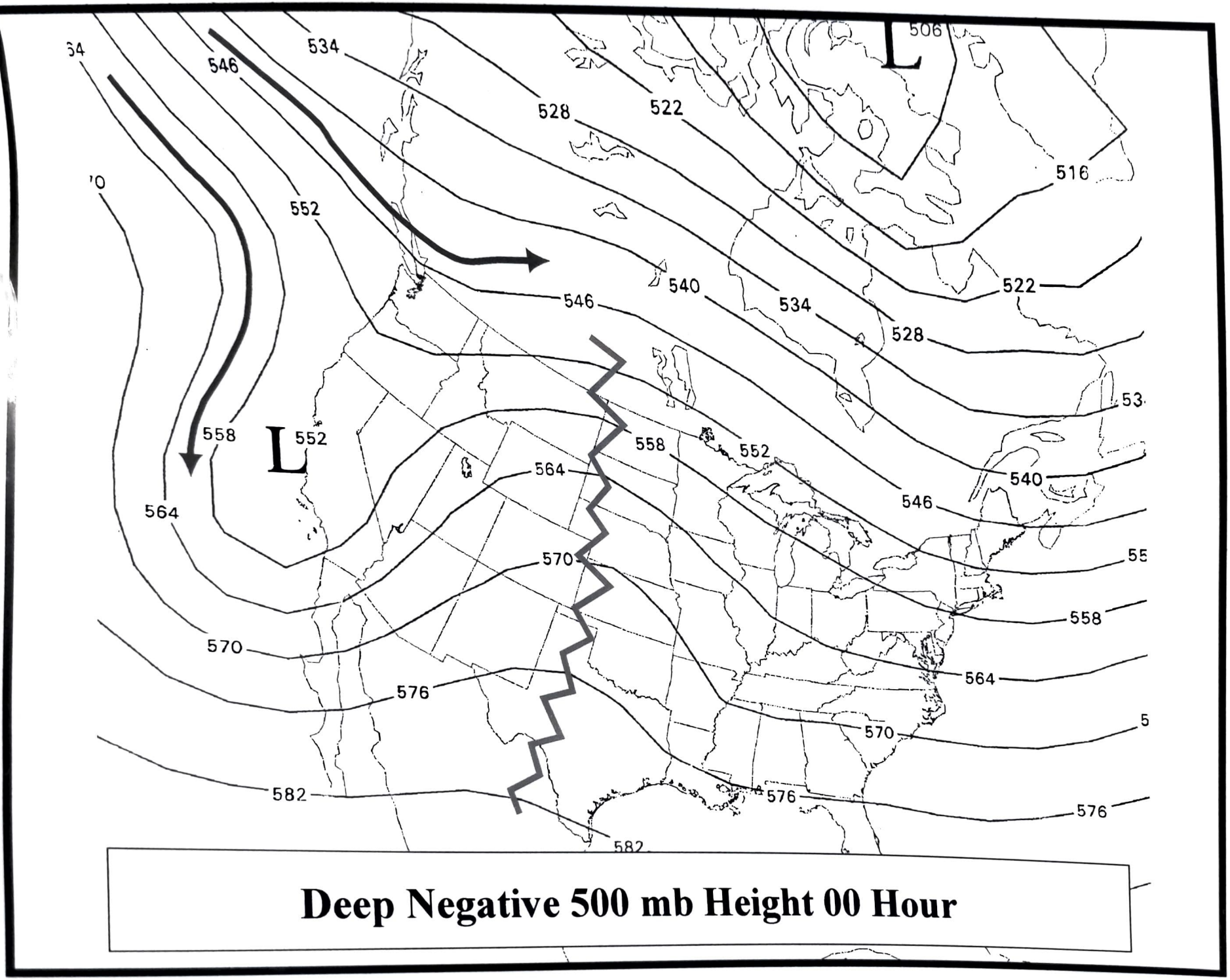
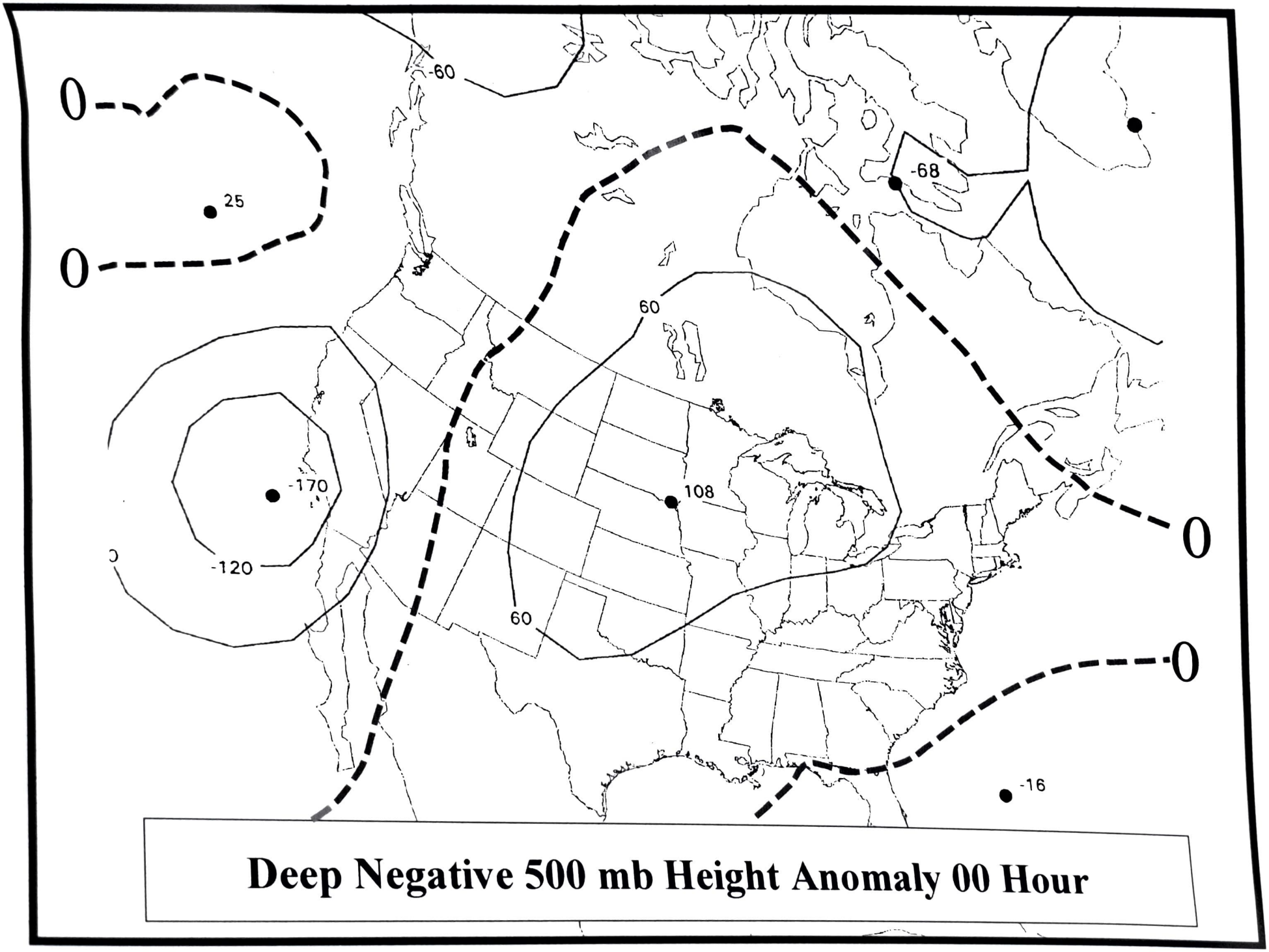
Deep Positive 500 mb Height 00 Hour



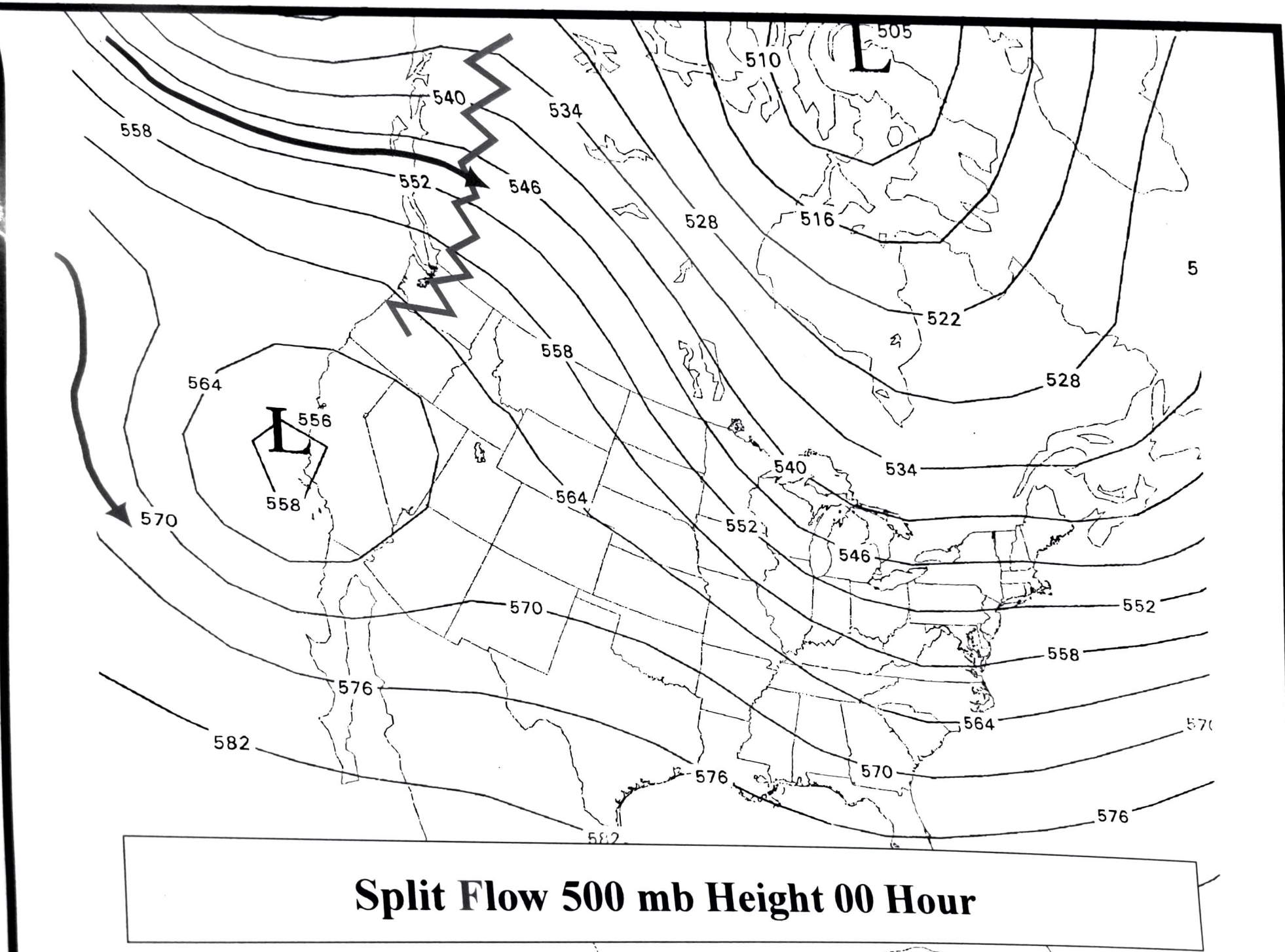
Deep Positive 500 mb Height Anomaly 00 Hour



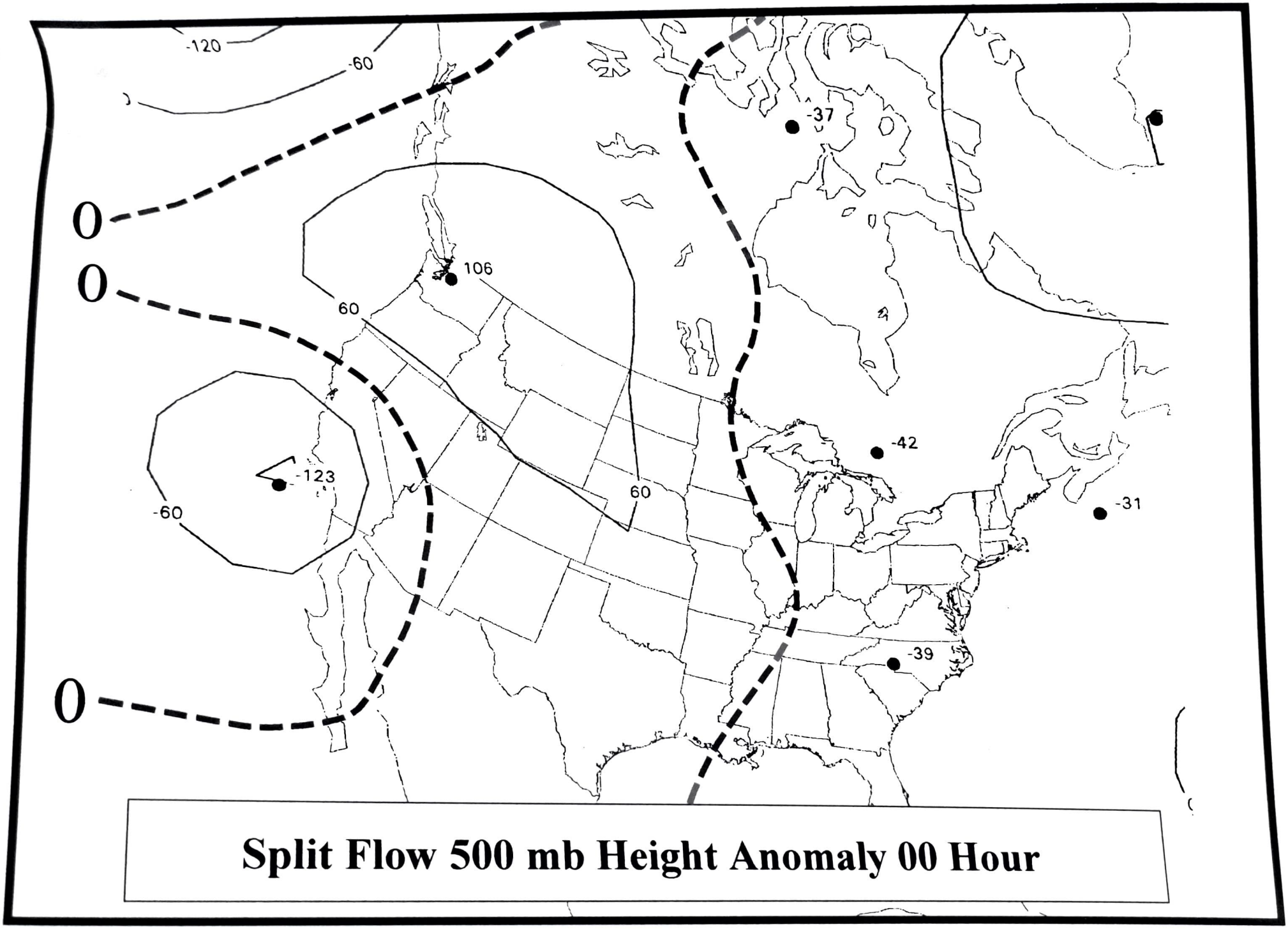
Deep Negative 500 mb Height 00 Hour



Deep Negative 500 mb Height Anomaly 00 Hour



Split Flow 500 mb Height 00 Hour



Split Flow 500 mb Height Anomaly 00 Hour

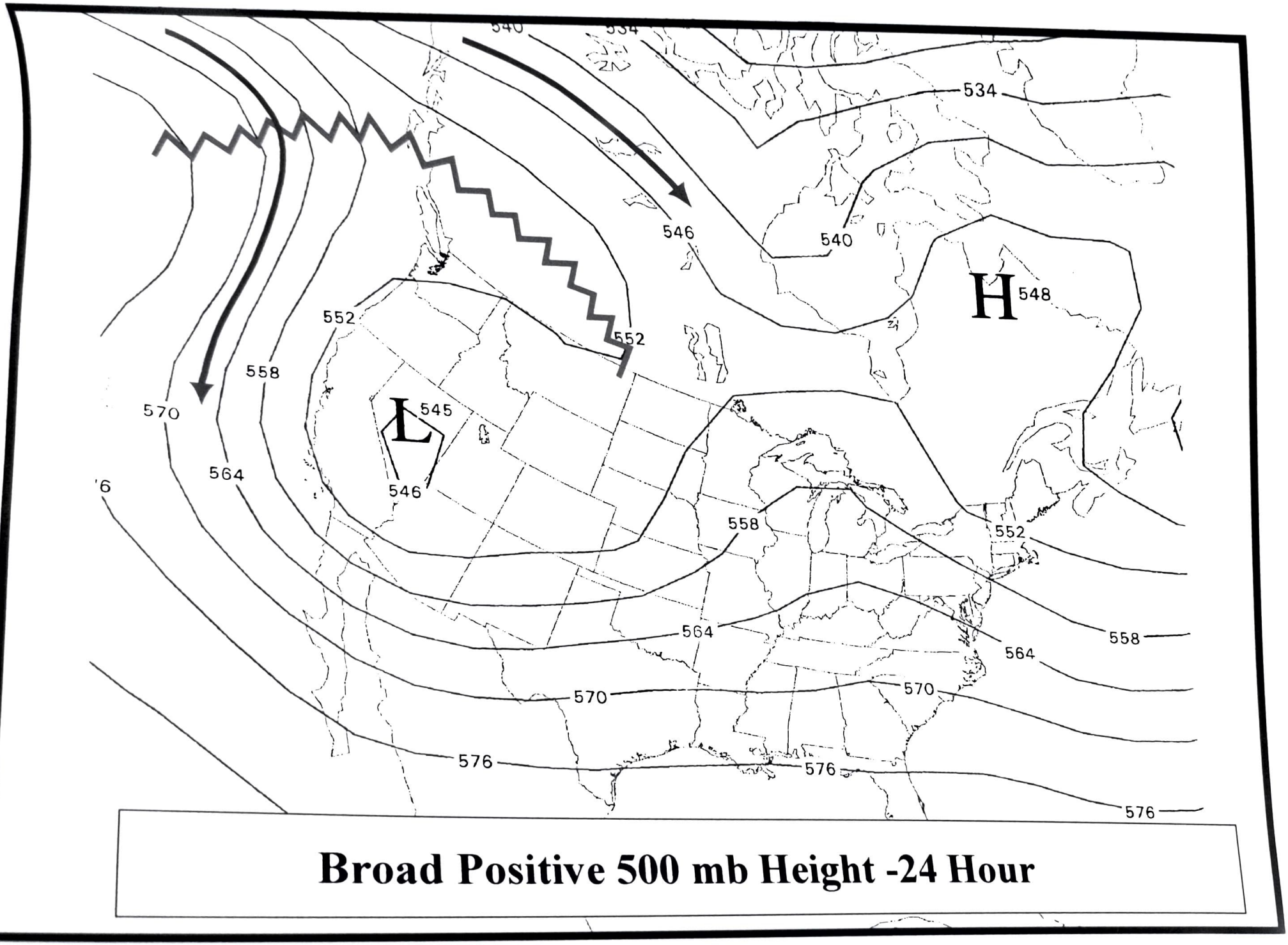
2) BROAD POSITIVE TILT TROUGH

The Broad Positive pattern produces the lowest mean liquid precipitation of the four types. It is important to identify this pattern type because it will normally require a Snow Advisory in portions of northern Arizona. This is the coldest of the four types identified. Once the trough lifts to the northeast and exits Arizona, precipitation ends.

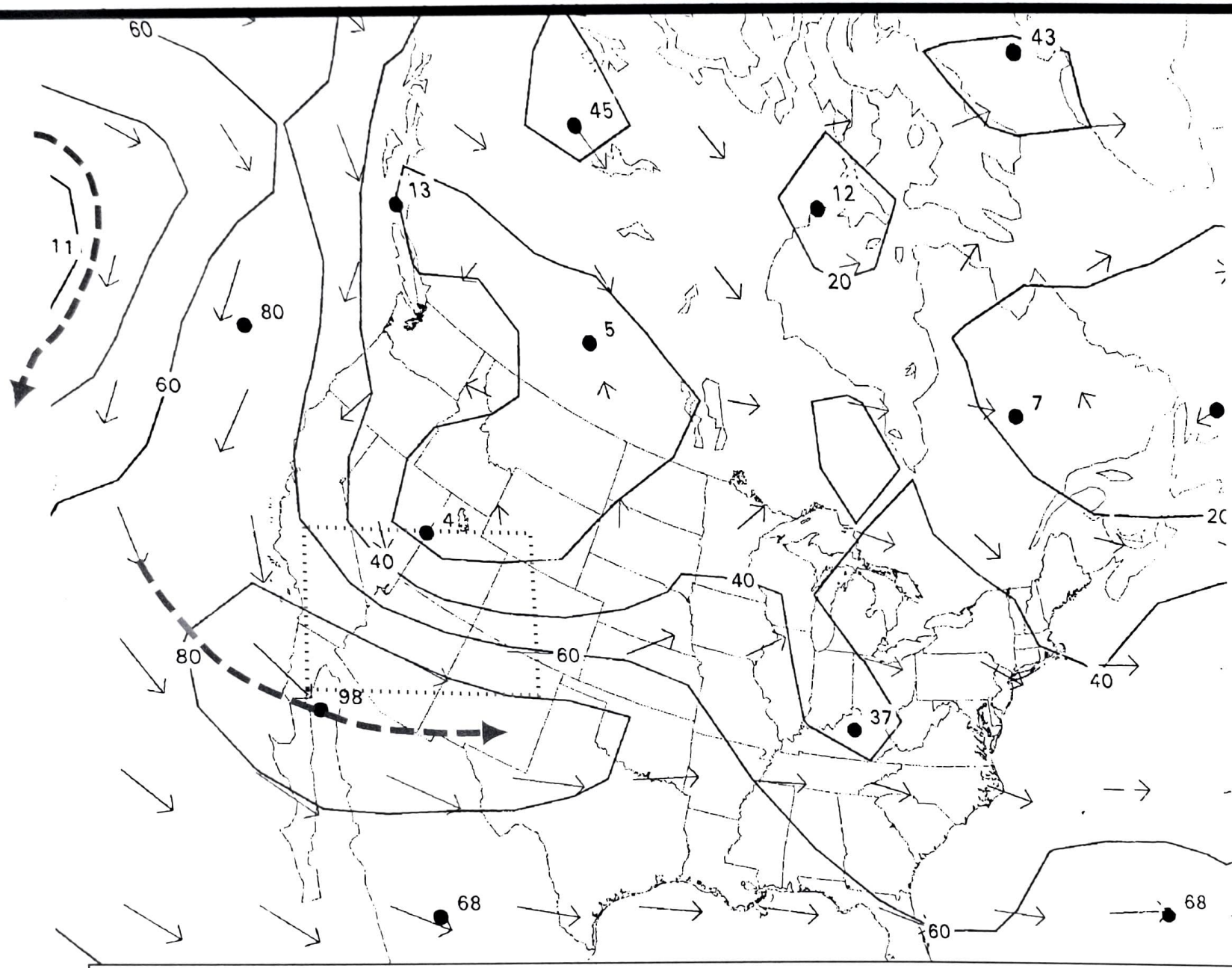
The important features to watch with this pattern are upper-level jet maxima at the 250-mb level propagating through the baroclinic zone surrounding the mid- to upper-level trough center. As these jet maxima features approach Arizona, the mid-level winds back to a more southerly direction enhancing mid-level warm advection and upward lift.

The table below shows some of the precipitation statistics at Flagstaff for the Broad Positive events. In every case this pattern produced precipitation in Flagstaff well before the low center propagated into California. The message here is that if there is a high degree of certainty that a broad and cold trough (central 500 mb height 550 dam or less) will set up over the west then forecast high pops at least a day in advance of the low center setting up over California.

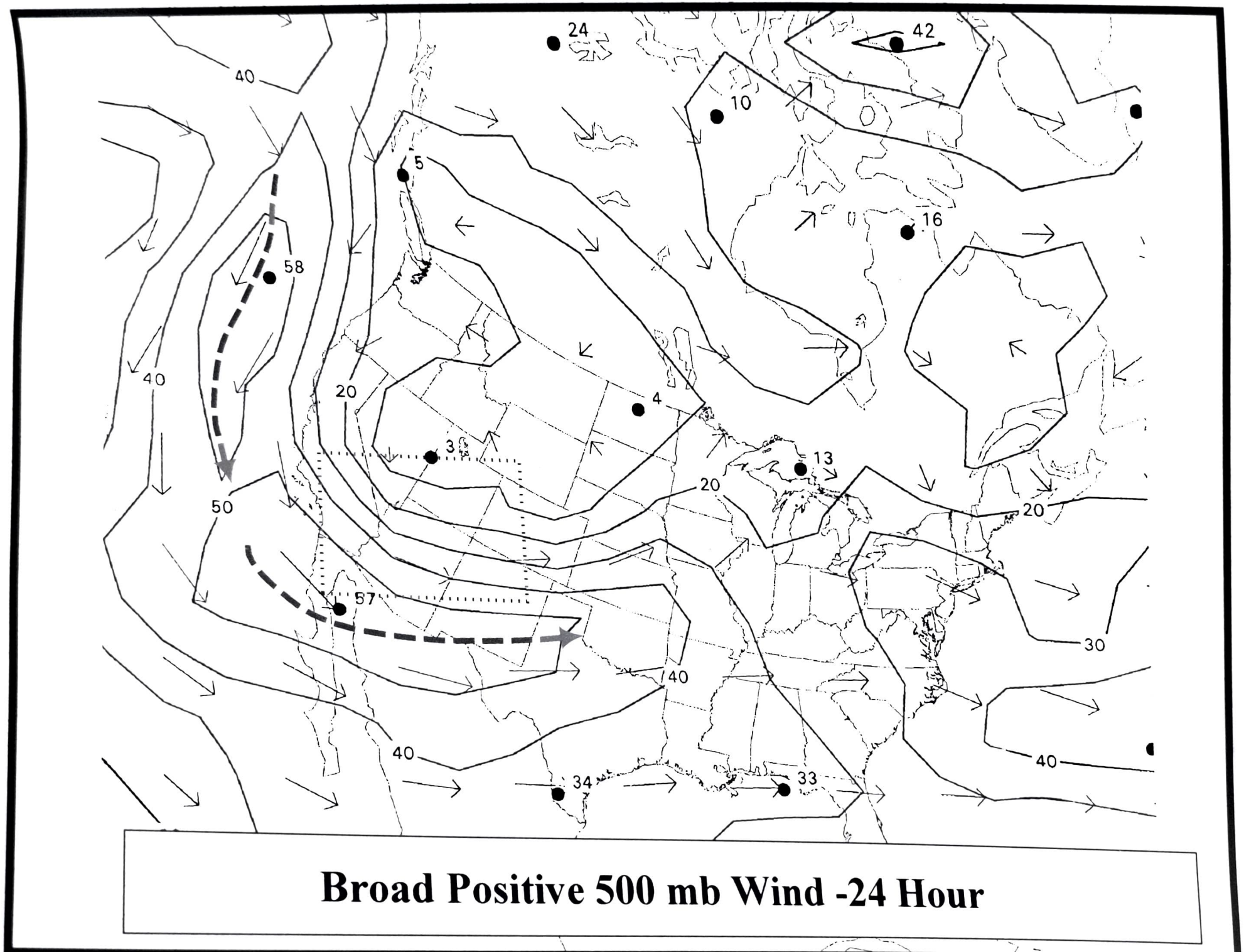
	Avg	Range	POP
Before	0.32	.01-.77	100%
Day 1	0.25	.01-.52	100%
Day 2	0.32	.01-.69	100%
Day 3	0.01	T-.01	25%



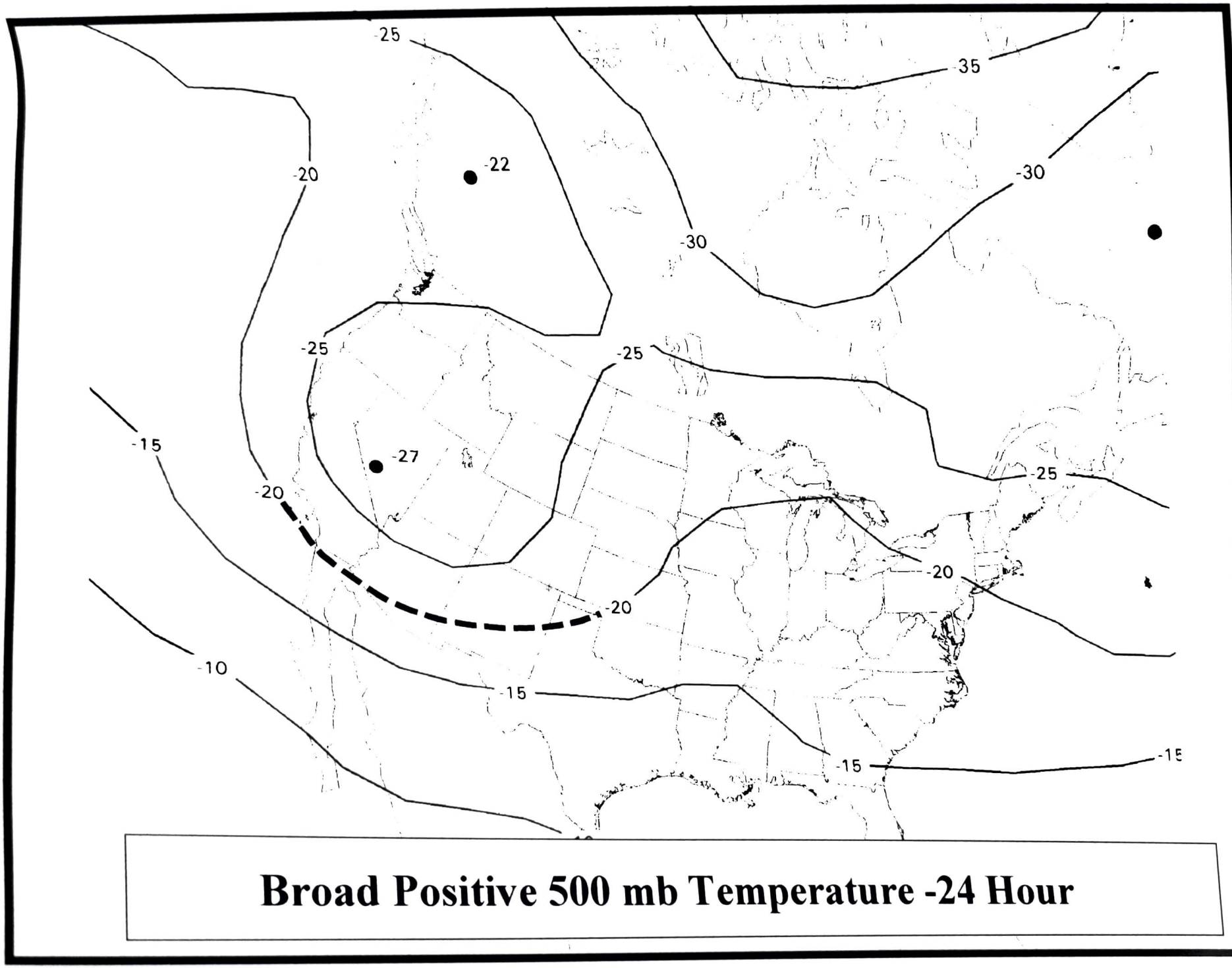
Broad Positive 500 mb Height -24 Hour



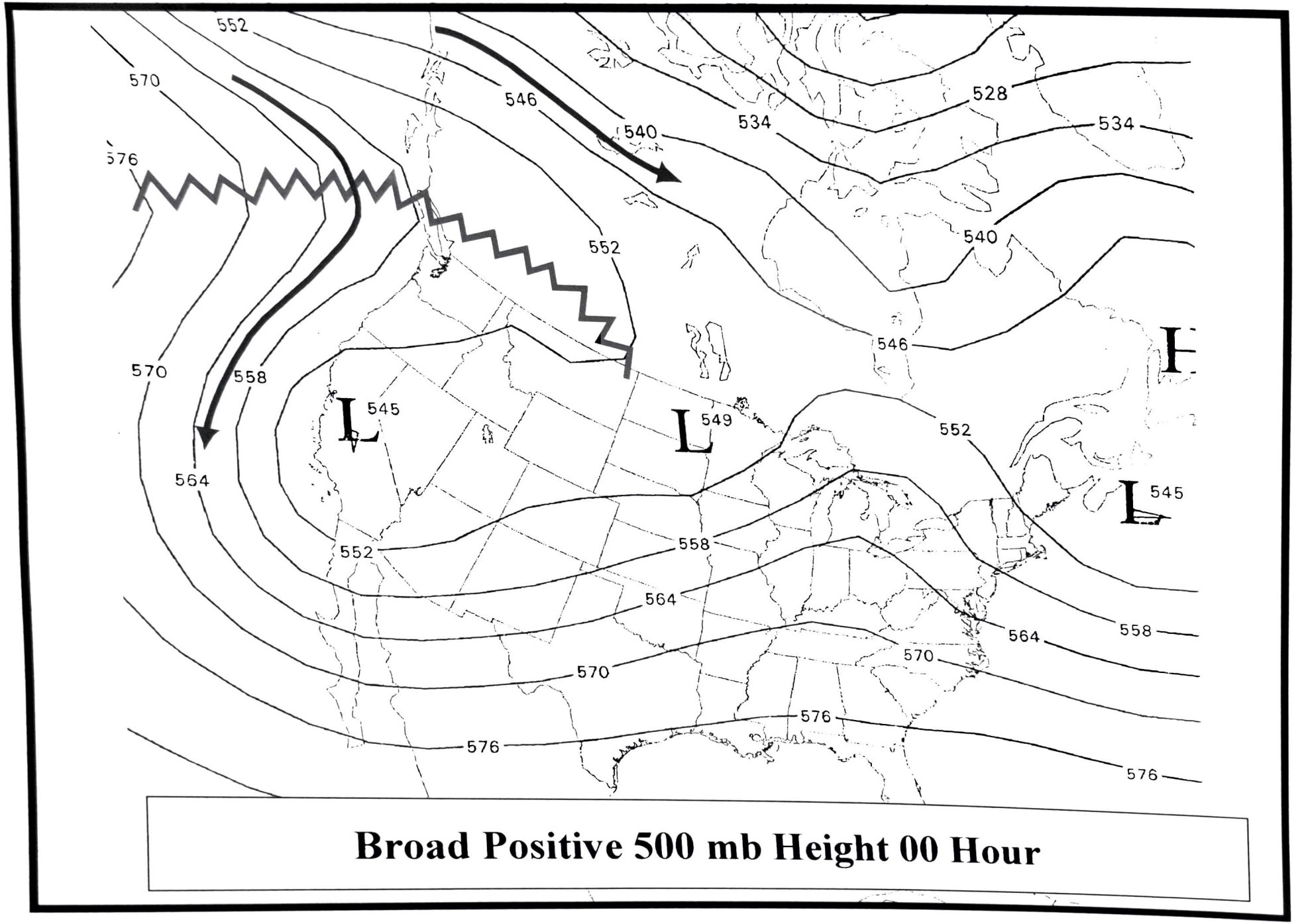
Broad Positive 250 mb Wind -24 Hour



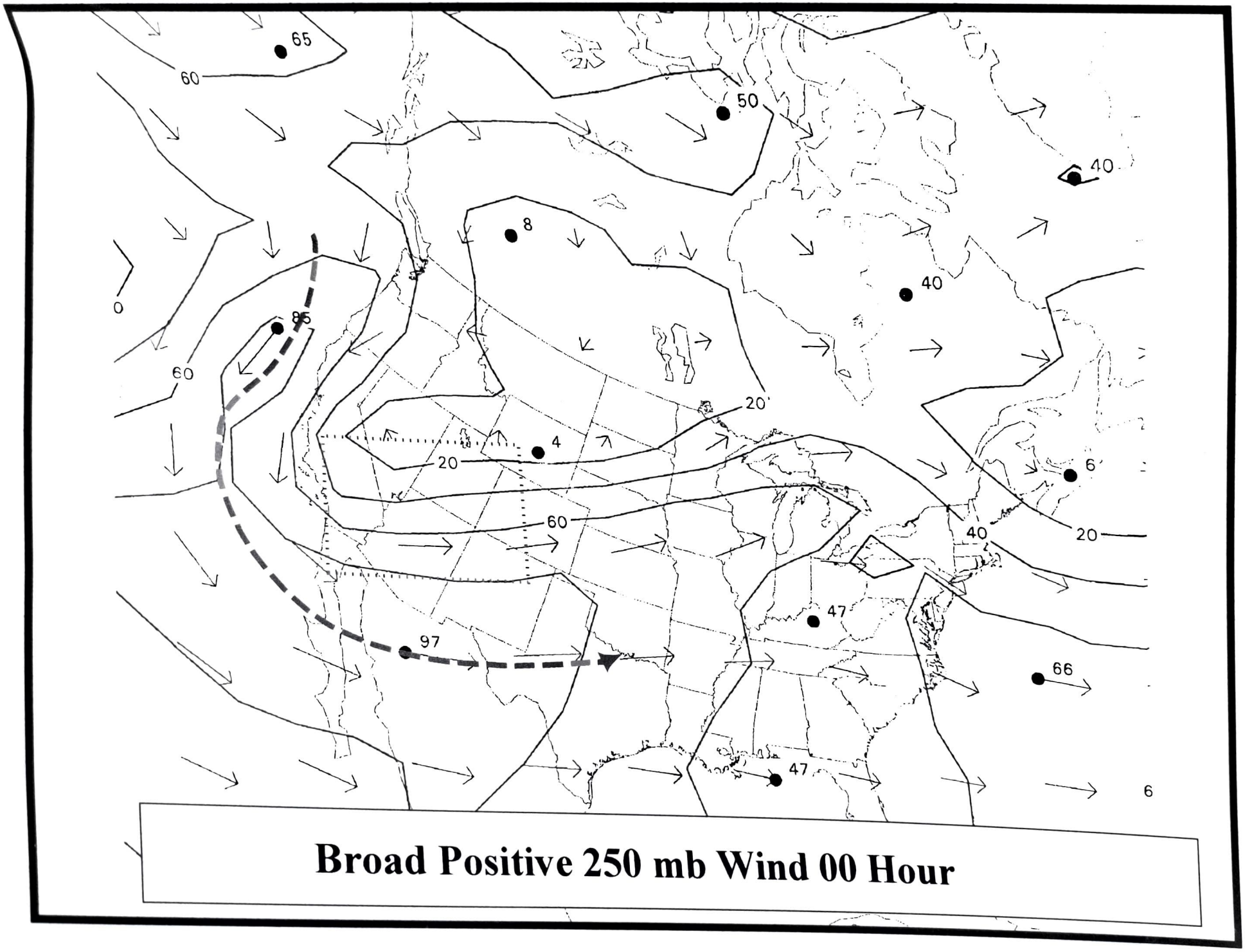
Broad Positive 500 mb Wind -24 Hour



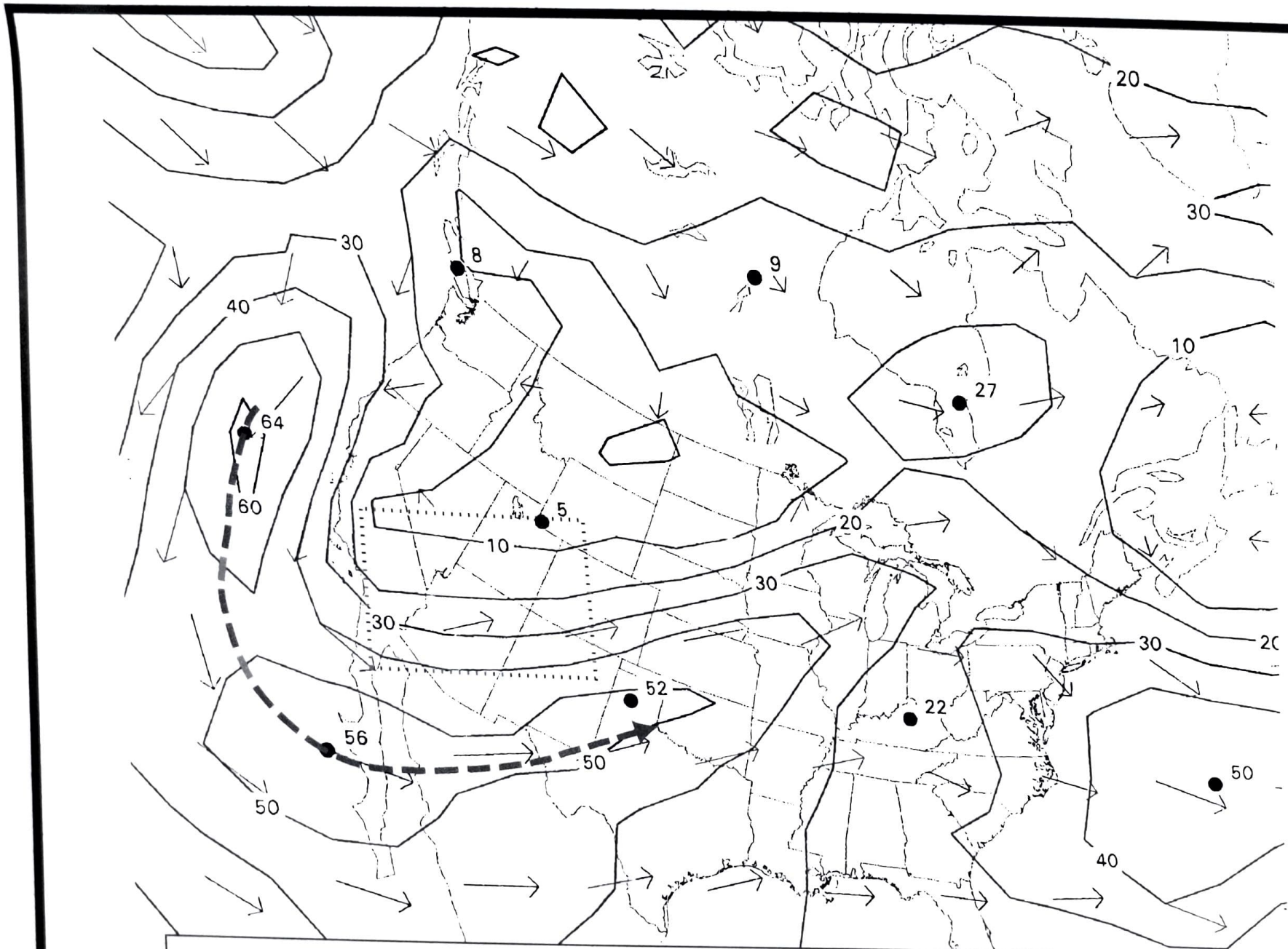
Broad Positive 500 mb Temperature -24 Hour



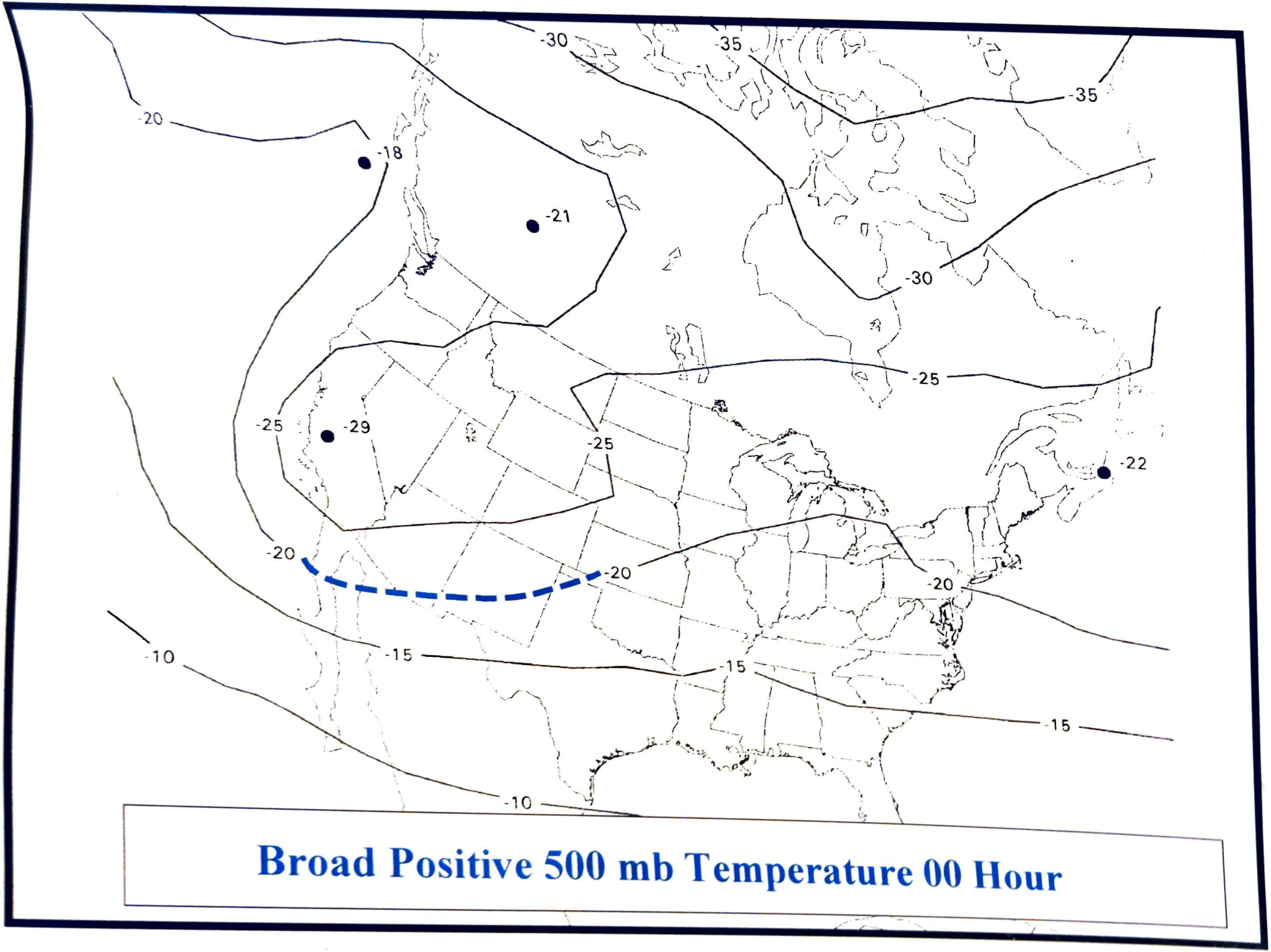
Broad Positive 500 mb Height 00 Hour



Broad Positive 250 mb Wind 00 Hour



Broad Positive 500 mb Wind 00 Hour



Broad Positive 500 mb Temperature 00 Hour

3) DEEP POSITIVE TILT TROUGH

The Deep Positive pattern produces the second highest mean liquid precipitation of the four types. It is important to identify the cases where the early onset of precipitation is likely (PRE cases) since they will almost always will require a Winter Storm Watch/Warning. In the PRE cases light precipitation often continues after the trough axis has exited Arizona (secondary short wave moving over residual moisture). In the POST cases precipitation tends to cease once the trough axis has exited into New Mexico.

Features to monitor when a Deep Positive pattern is developing are:

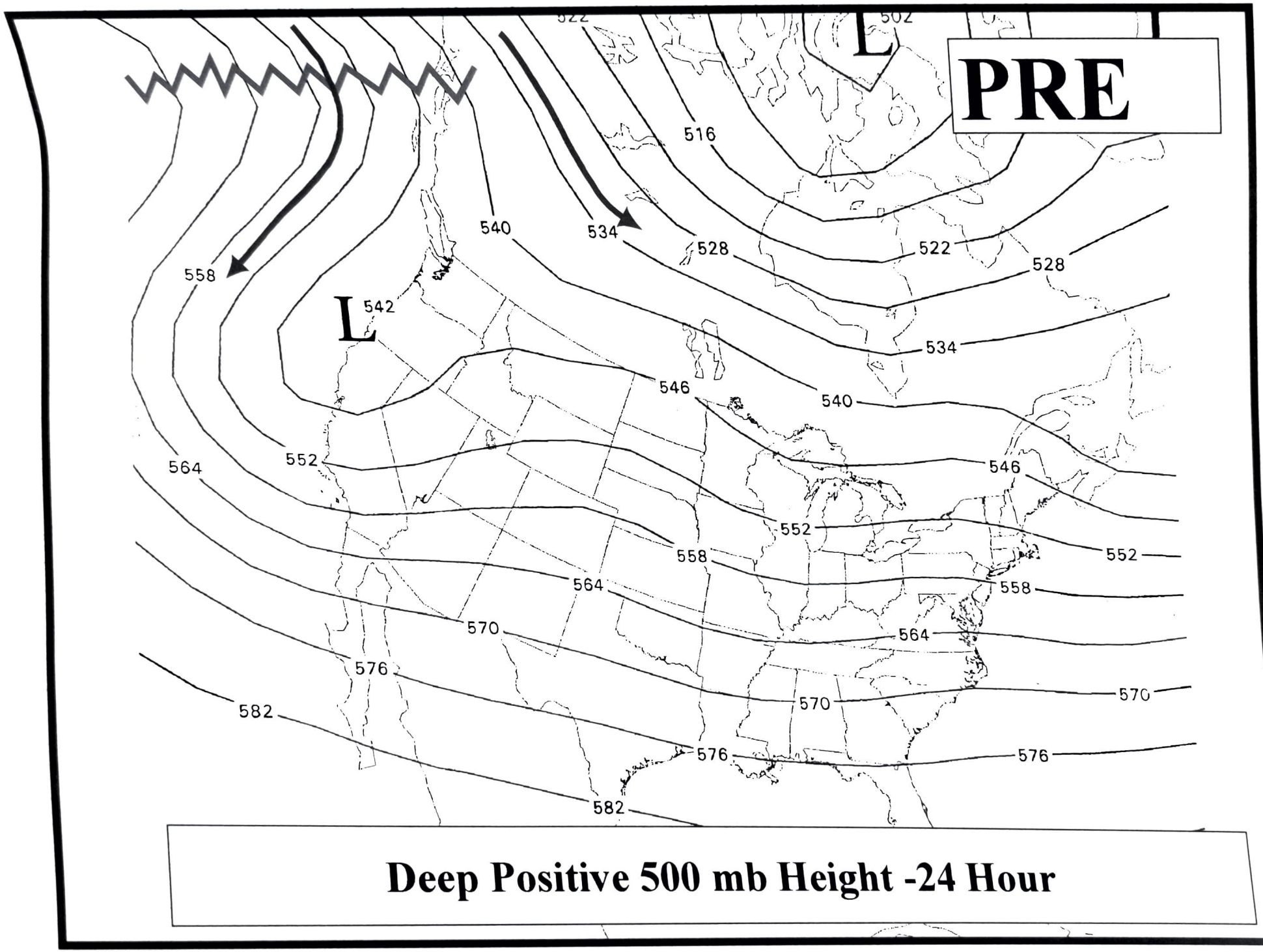
24 hours before the low center has developed over California (see charts):
1) The 500 mb low center in the PRE case is much deeper than the POST with a closed circulation already forming. The upstream ridging the PRE case has more amplitude.
2) The jet stream at 250 and 500 mb to the south and southeast of the developing low in the PRE case is 100 and 60 knots respectively. In the post case the 250 and 500 mb jet speed is 70 and 30 knots respectively.
3) In the PRE cases a northwest to southeast wind speed gradient is located across Nevada which at 250 mb is 70 knots and at 500 mb is 50 knots. The POST cases have a weaker gradient.
4) The -20 degree Celsius isotherm at 500 mb runs across central Arizona in the PRE case where as in the POST case it runs across central Nevada.

When the low is over southern California (see charts):
1) The jet stream at 250 and 500 mb to the south and southeast of the low remains 30 to 40 knots stronger than in the POST cases with much more wind speed-gradient across northern Arizona.

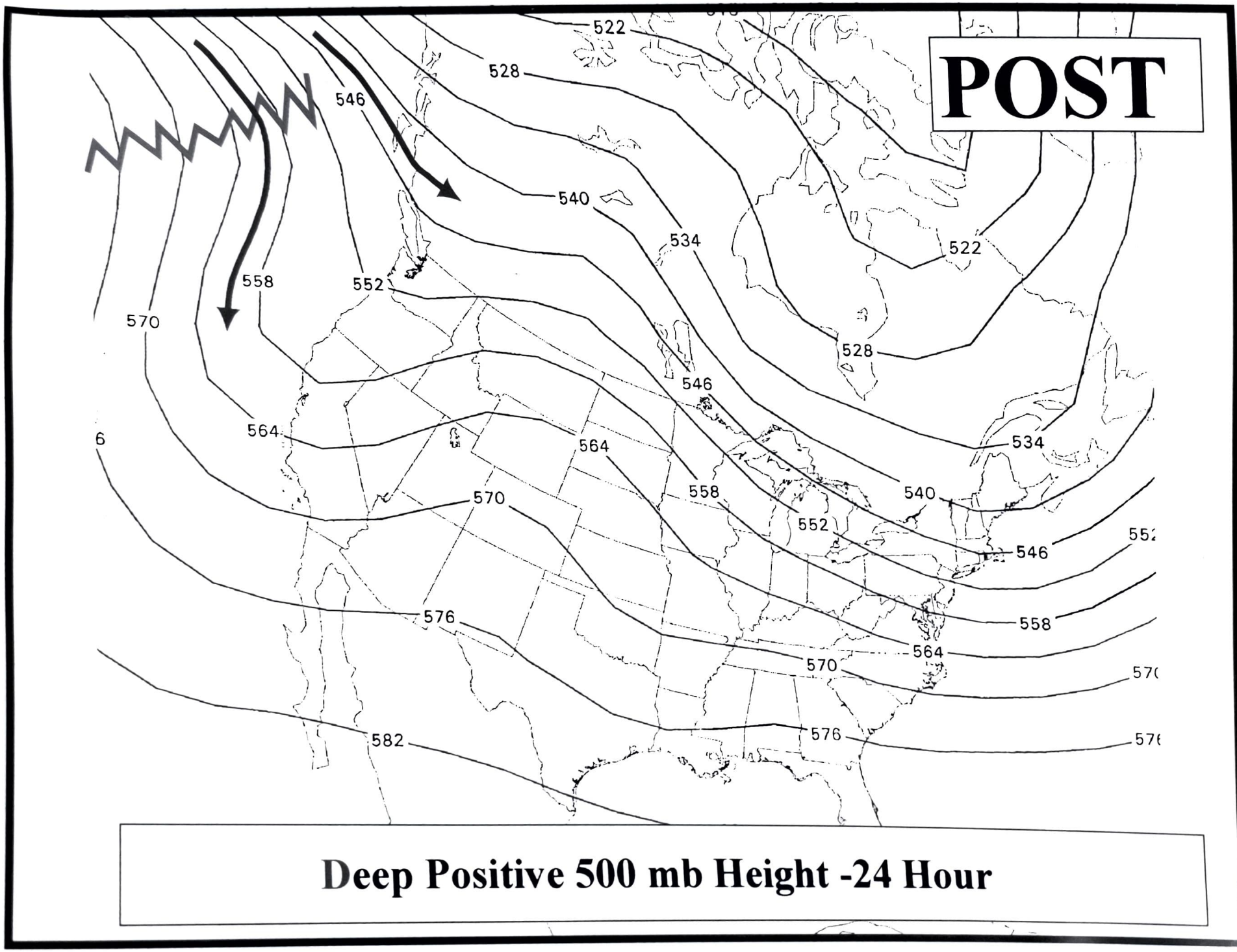
In the PRE cases precipitation probably starts before frontal passage after a period of extended and strong dynamics. However, most of the precipitation comes in the post frontal air mass where strong warm advection over the frontal boundary and upslope southwest flow force a saturated air mass to produce heavy snow.

The PRE version of this storm produces precipitation 30 % of the time before the low center reaches California and 100 percent of the time by the time the low center is over central to southern portions of California (see table below). None of the POST cases of the Deep Positive pattern produced precipitation at Flagstaff until the mid-level cold core moved into southeast California and was approaching western Arizona.

	PRE				**POST**		
	Avg	Range	POP		Avg	Range	POP
Before	1.48	0-1.91	29%				
Day 1	0.52	.31-.98	100%				
Day 2	0.24	.06-.80	100%	Day 2	0.39	0-.77	75%
Day 3	0.20	0-.24	30%	Day 3	0.05	0-.05	25%
After	0.38	0-.94	43%				



Deep Positive 500 mb Height -24 Hour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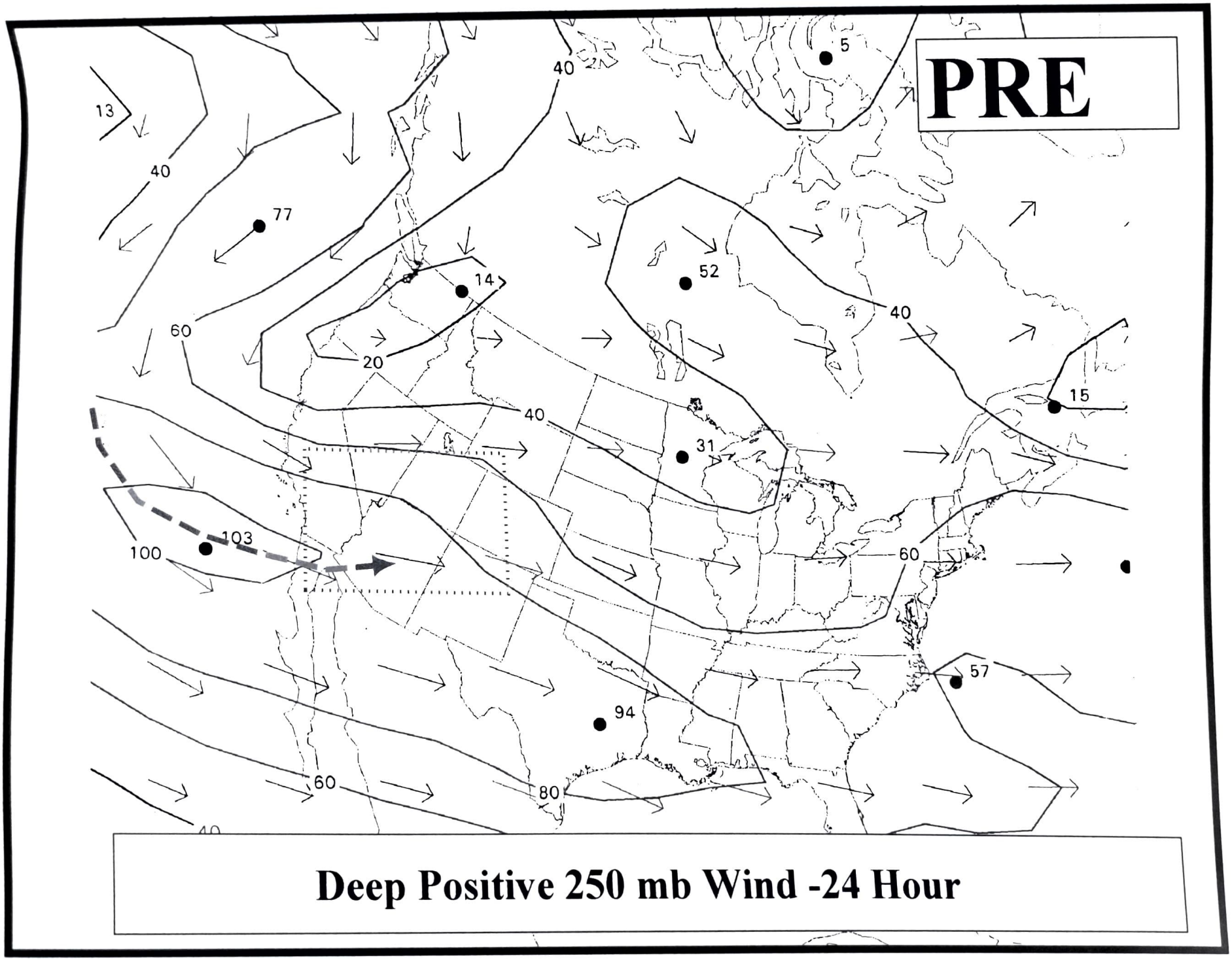
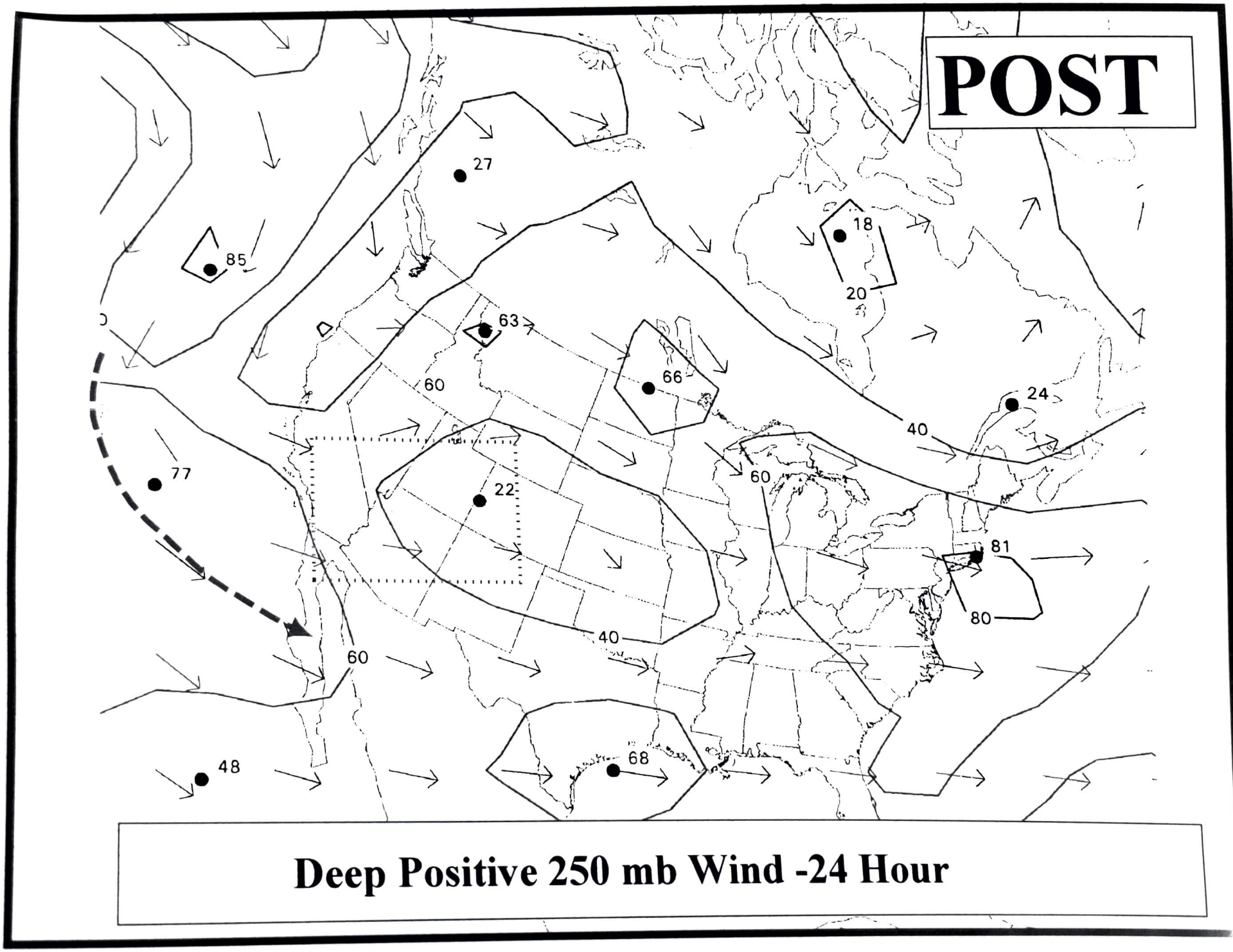
Deep Positive 500 mb Height -24 Hour



Deep Positive 250 mb Wind -24 Hour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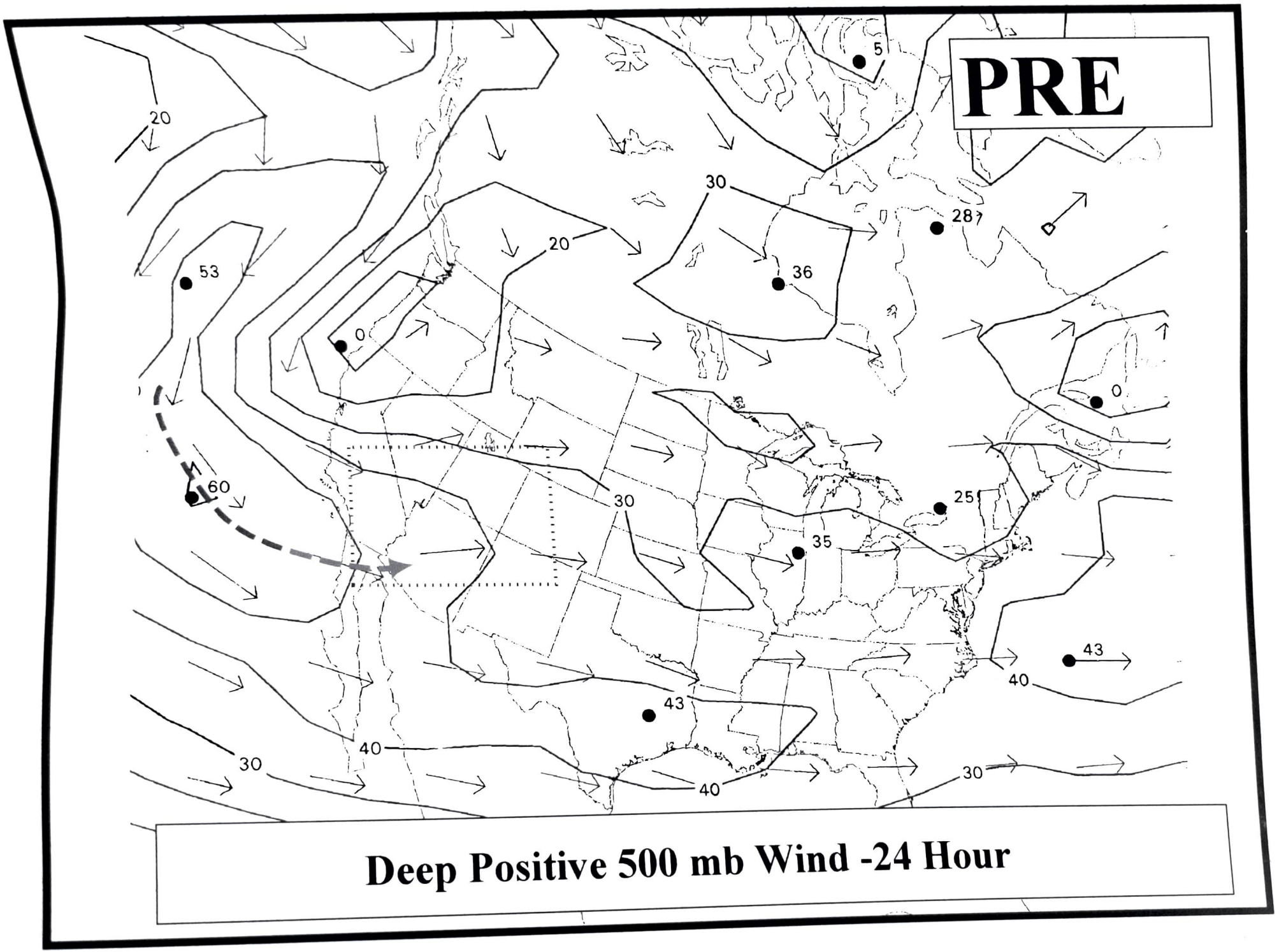
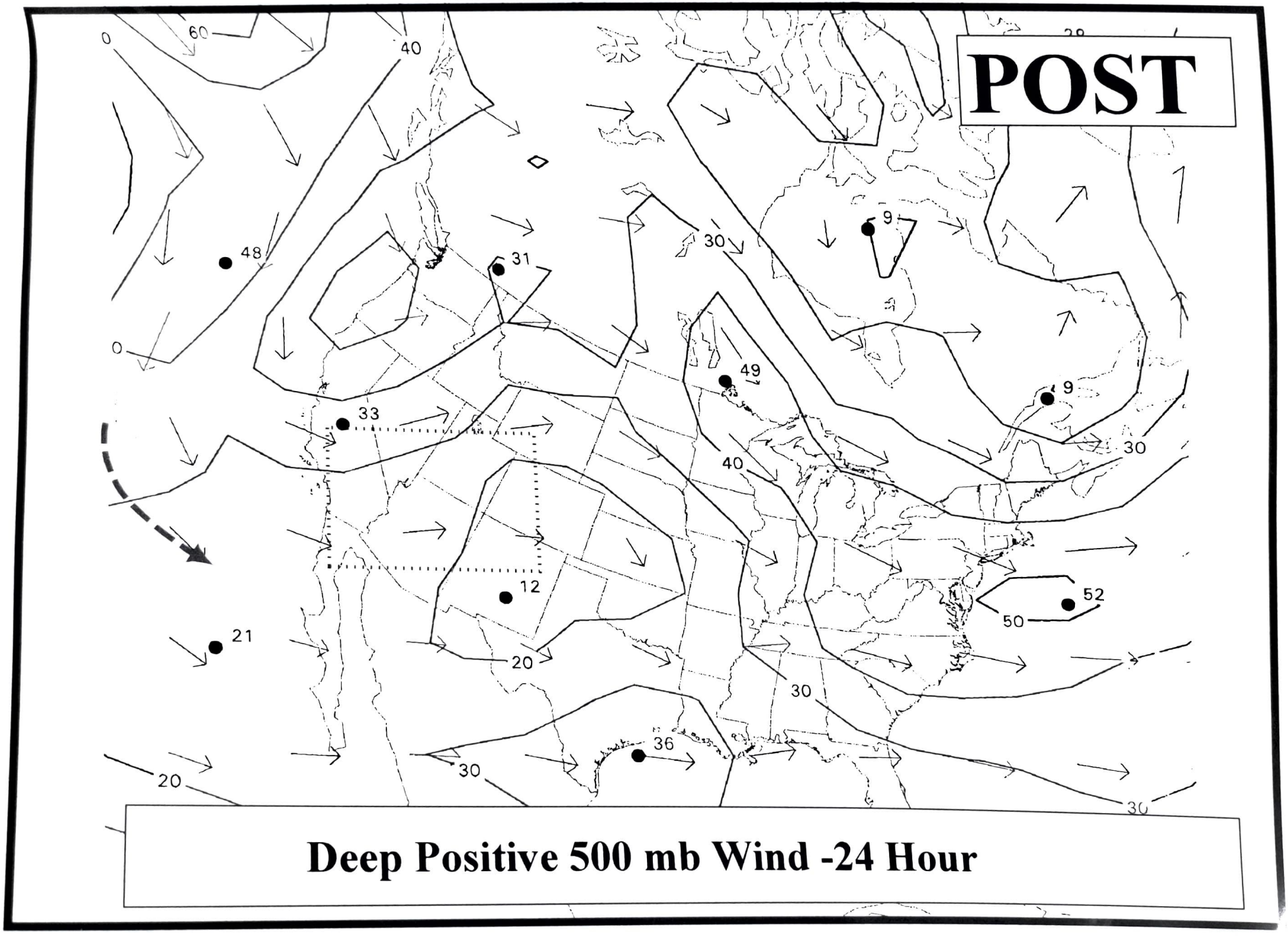
Deep Positive 250 mb Wind -24 Hour



Deep Positive 500 mb Wind -24 Hour



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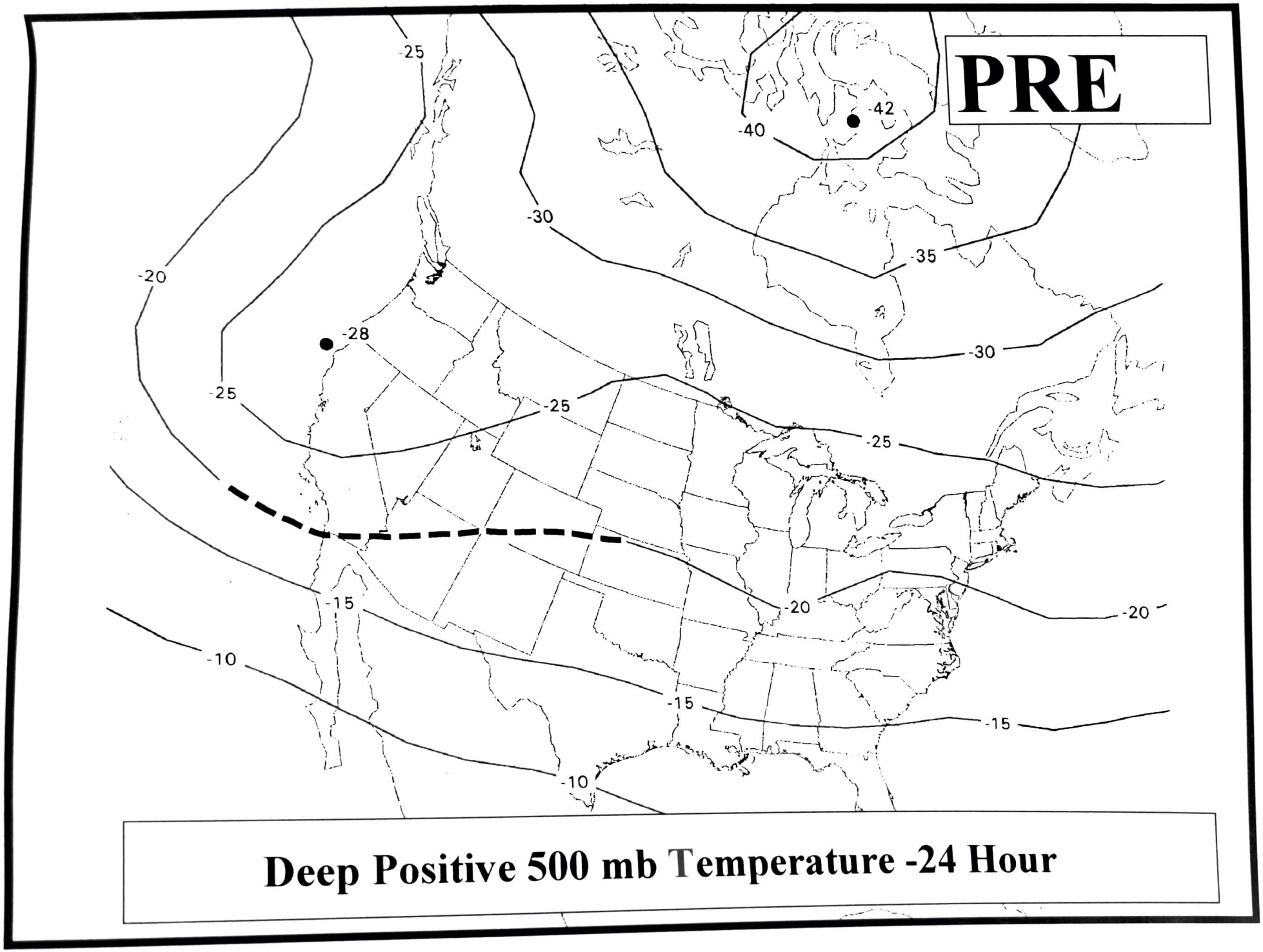
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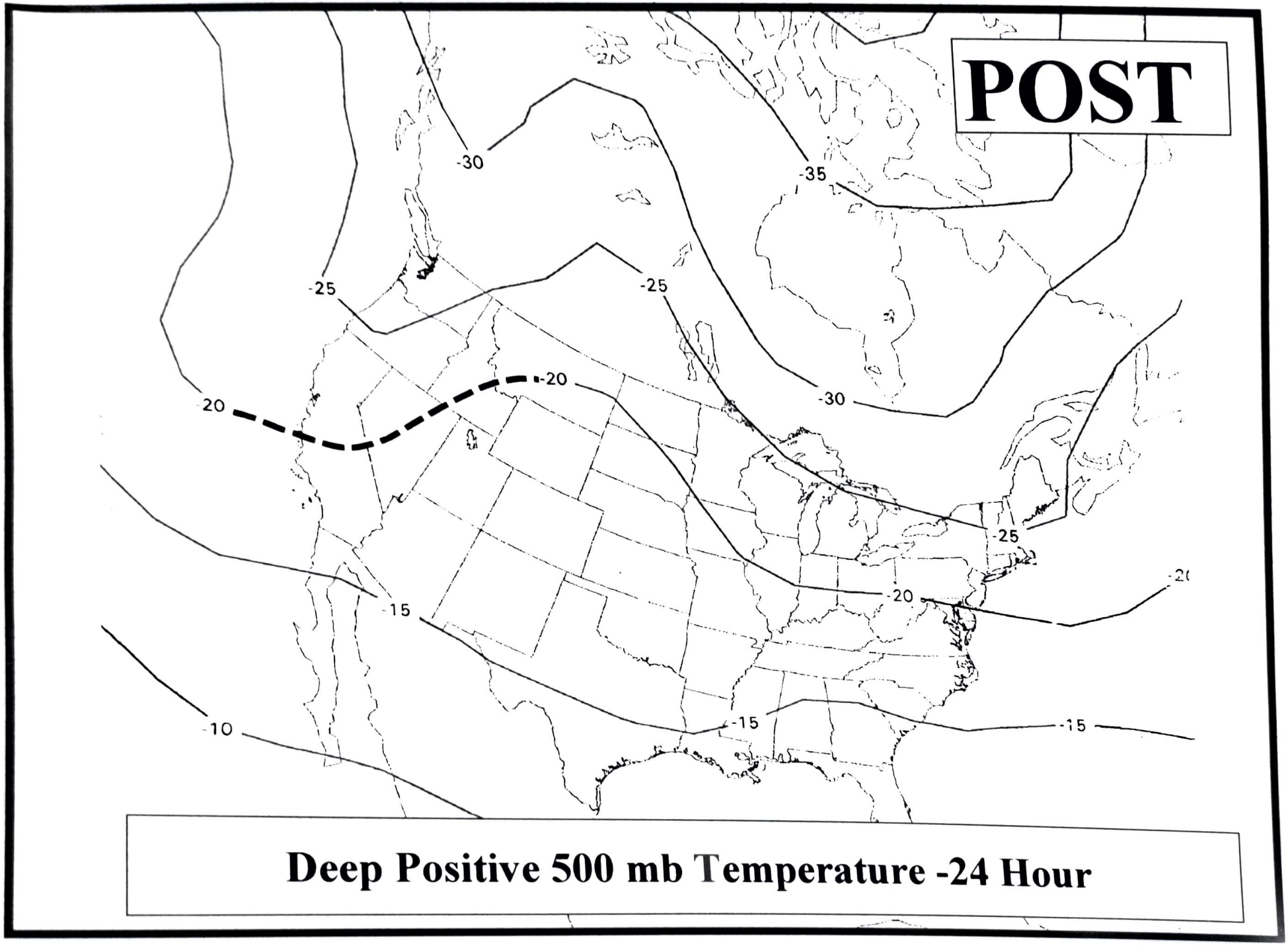
Deep Positive 500 mb Temperature -24 Hour



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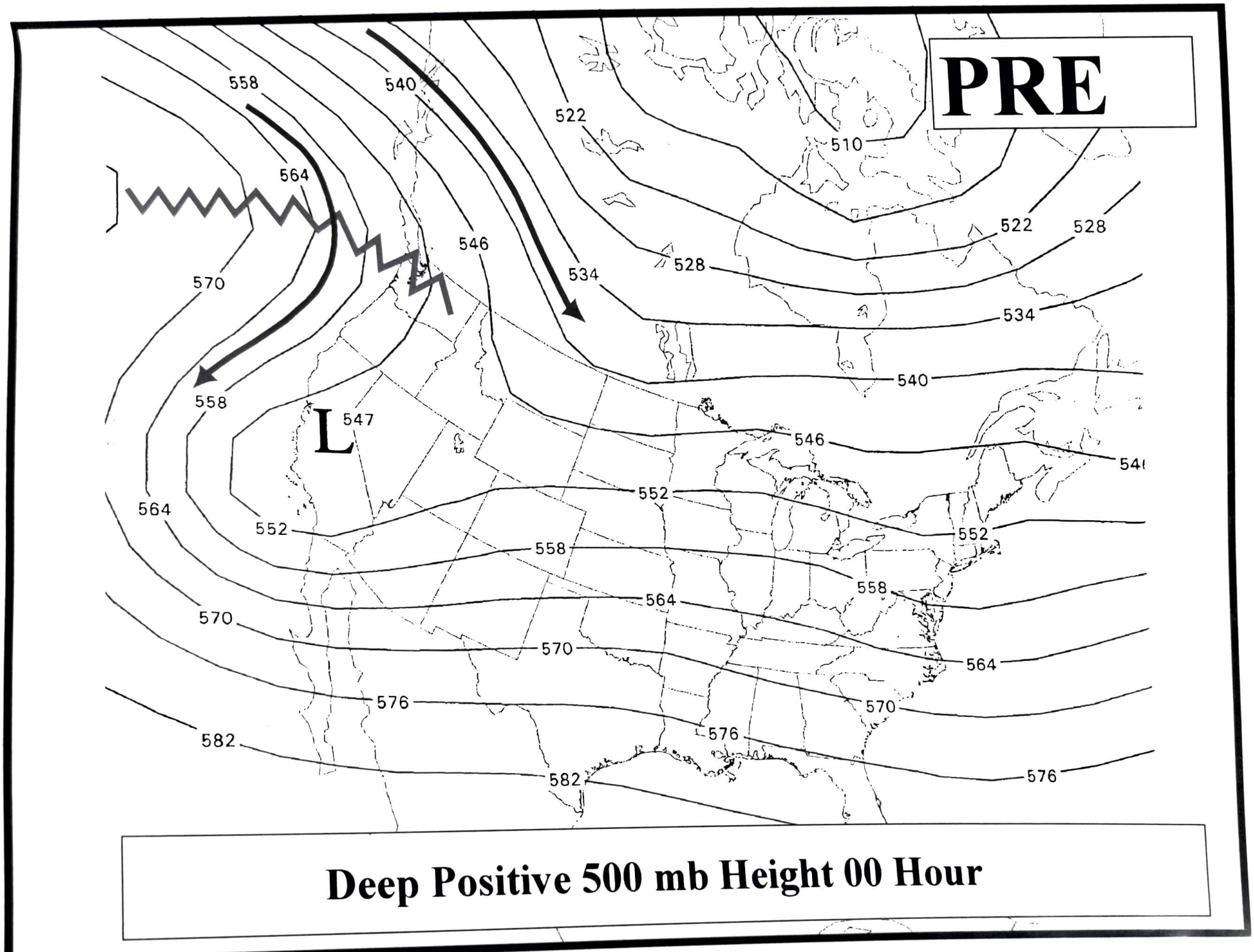
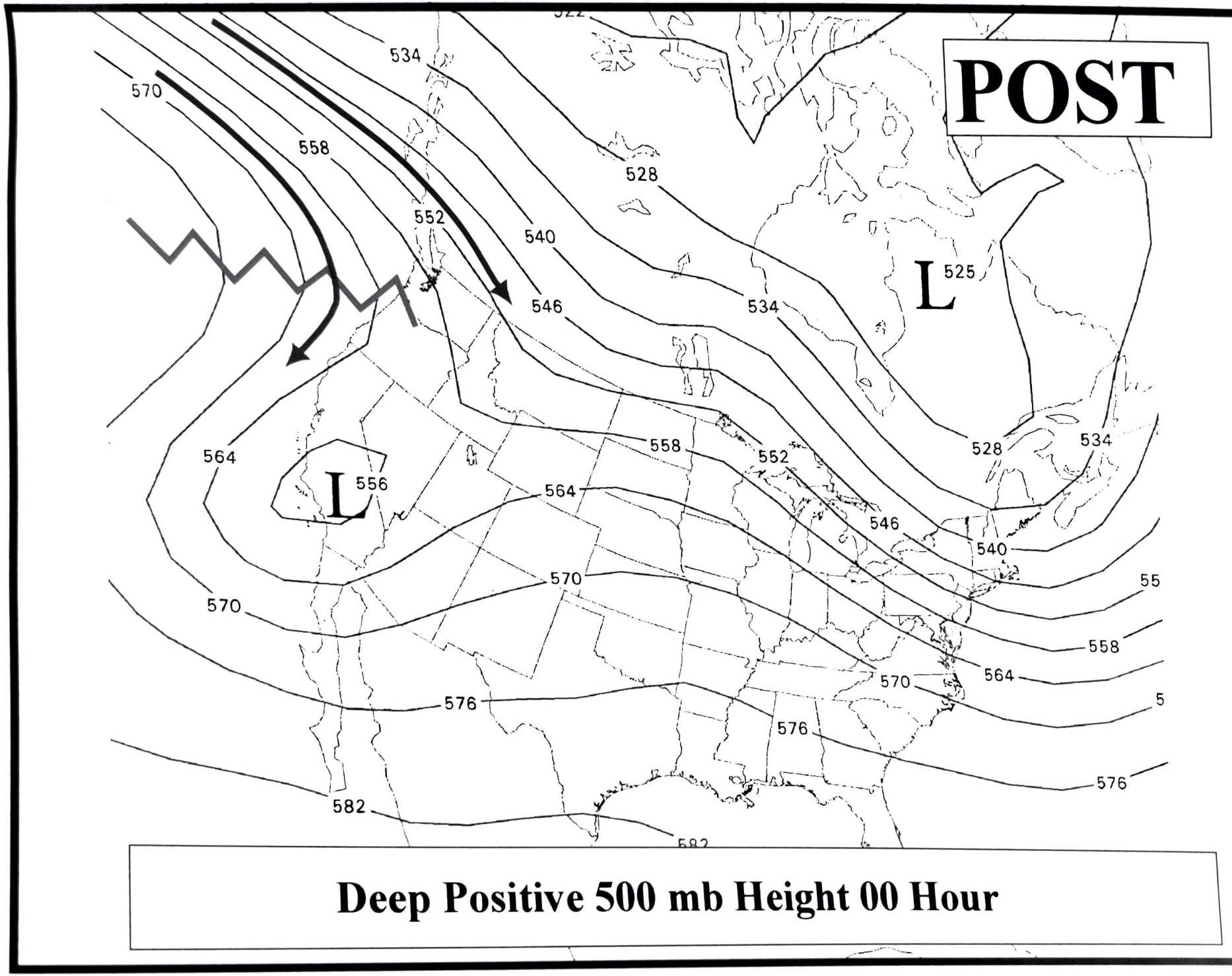


Deep Positive 500 mb Height 00 Hour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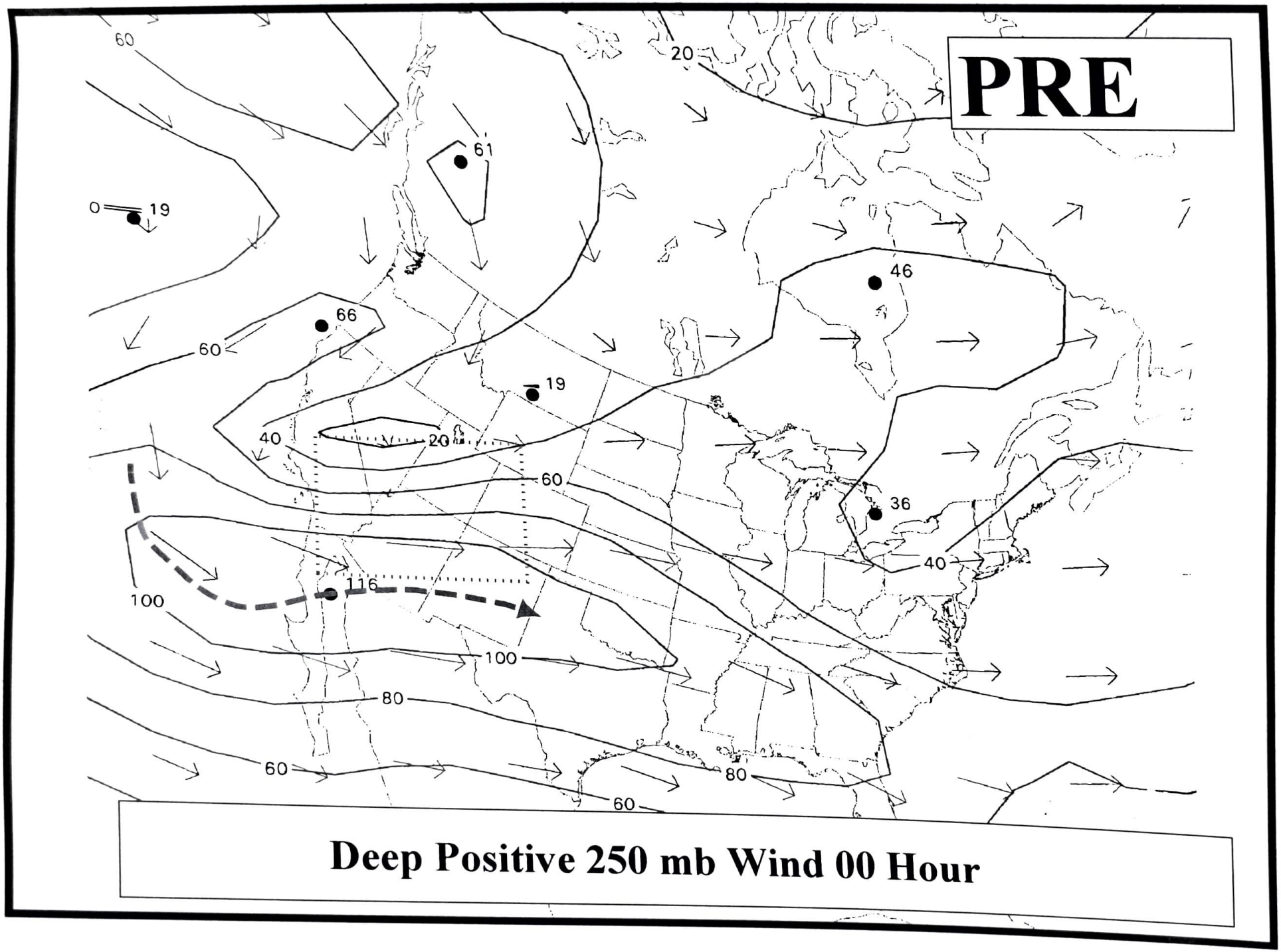
Deep Positive 500 mb Height 00 Hour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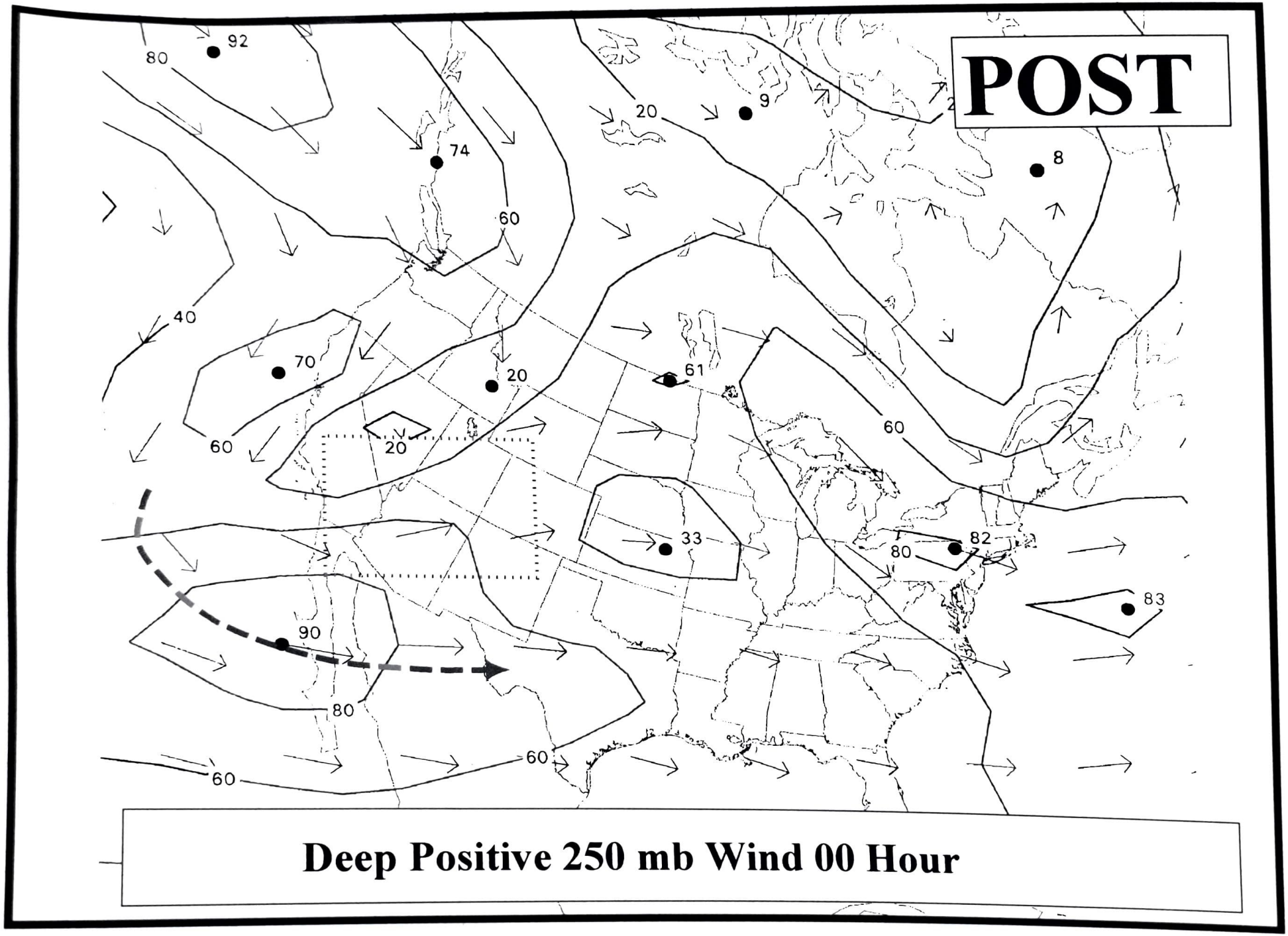
Deep Positive 250 mb Wind 00 Hour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9
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33
82
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83
90
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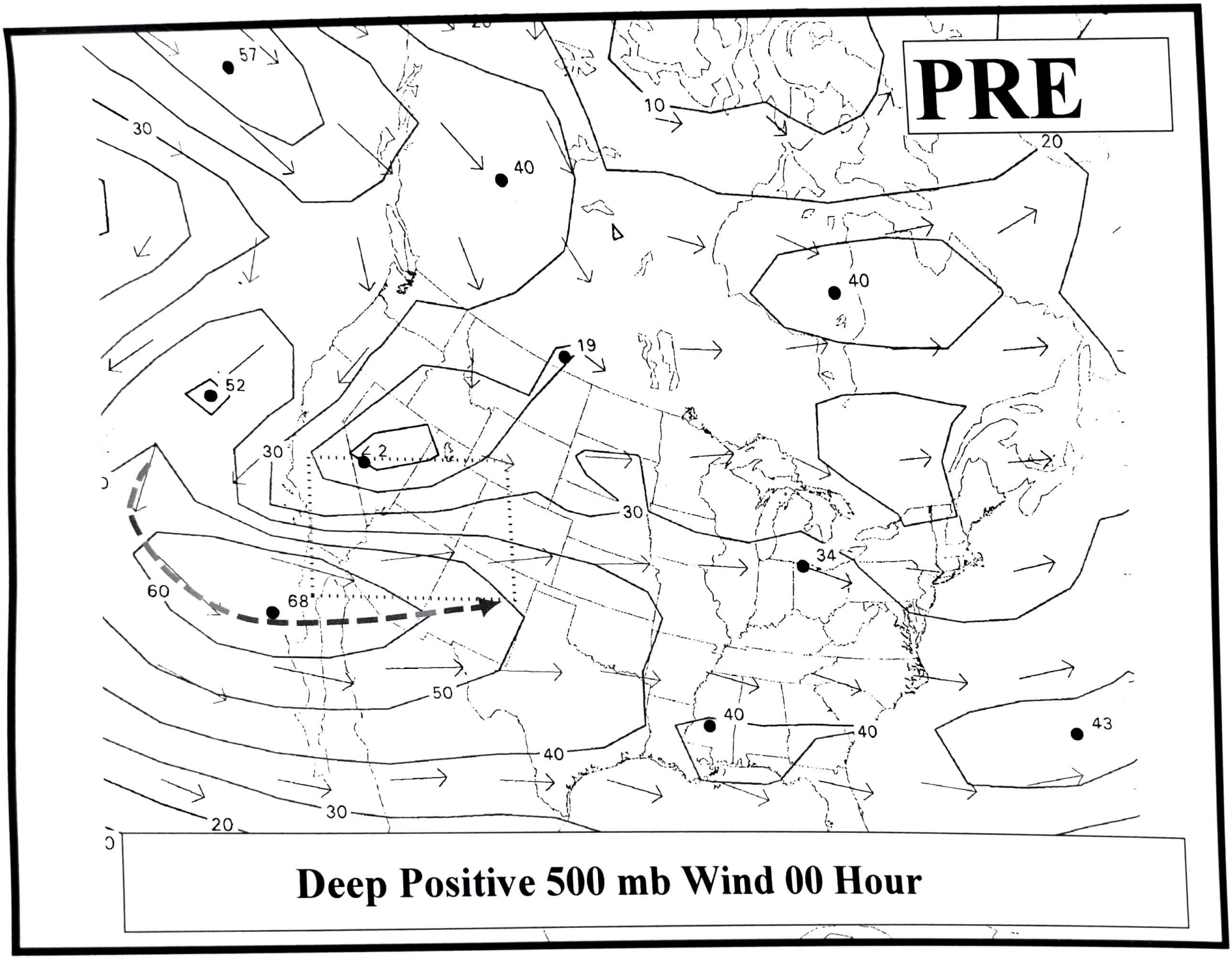
60
Deep Positive 250 mb Wind 00 Hour


PRE
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68
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20
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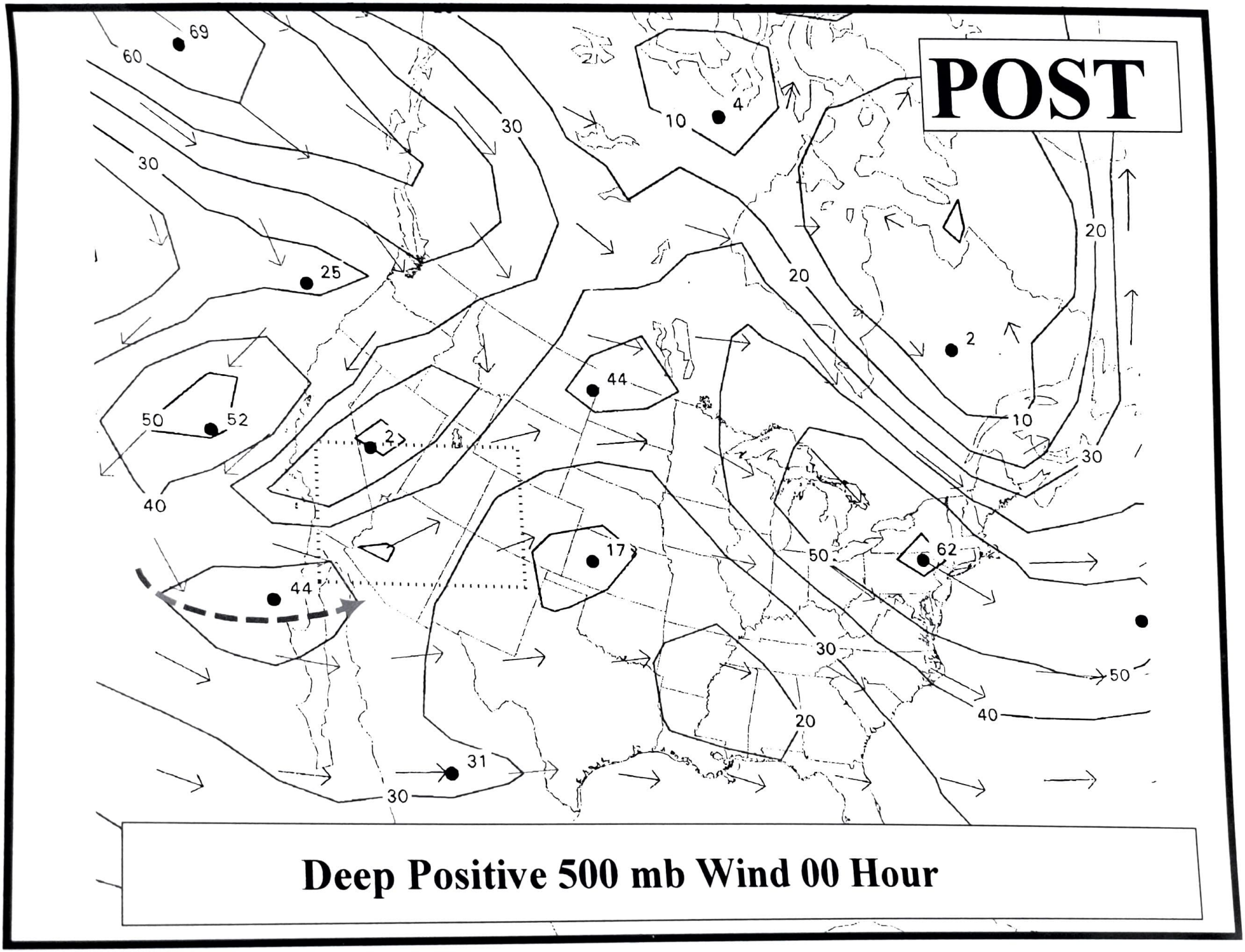
POST
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62
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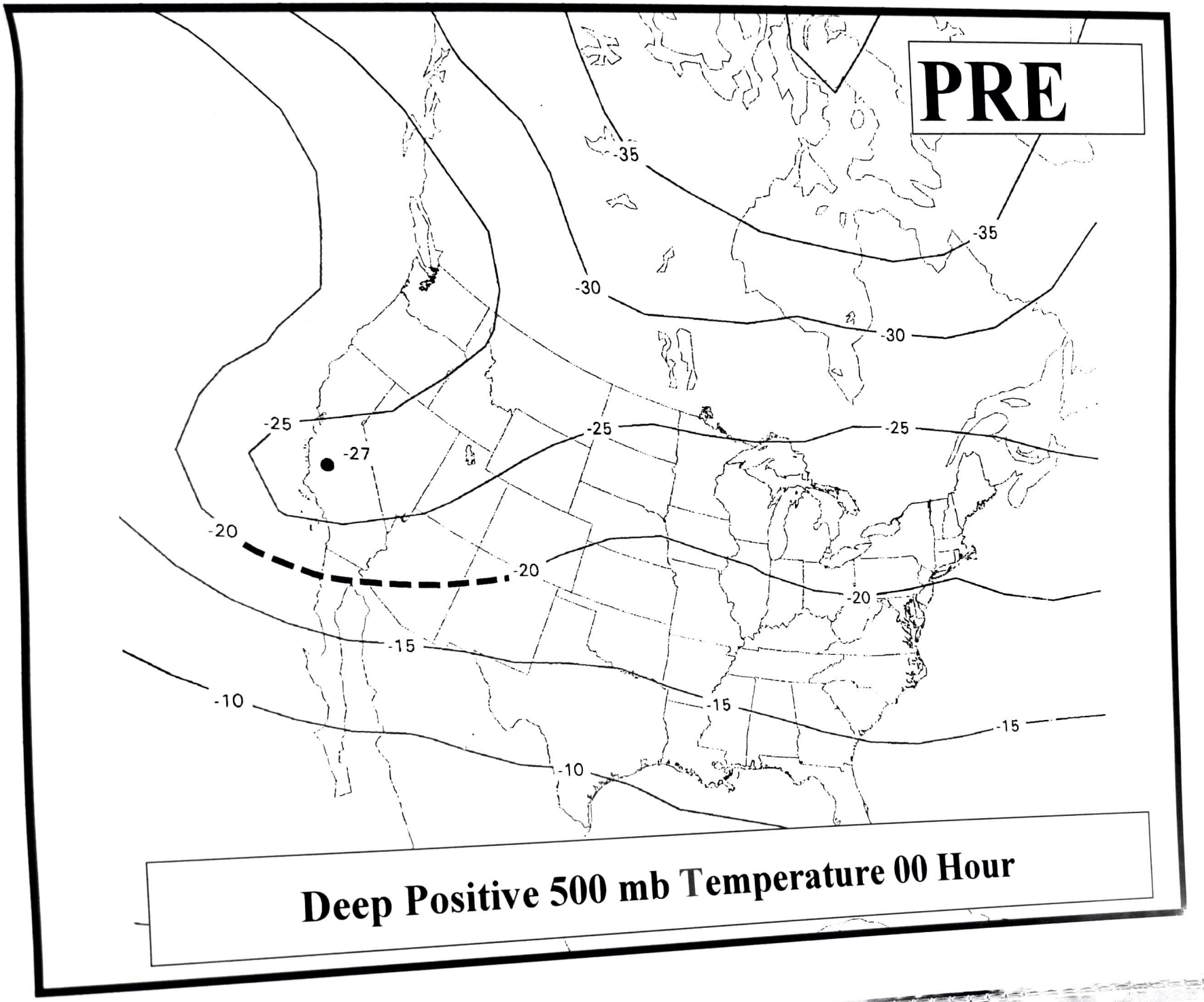
31
30
Deep Positive 500 mb Wind 00 Hour


PRE
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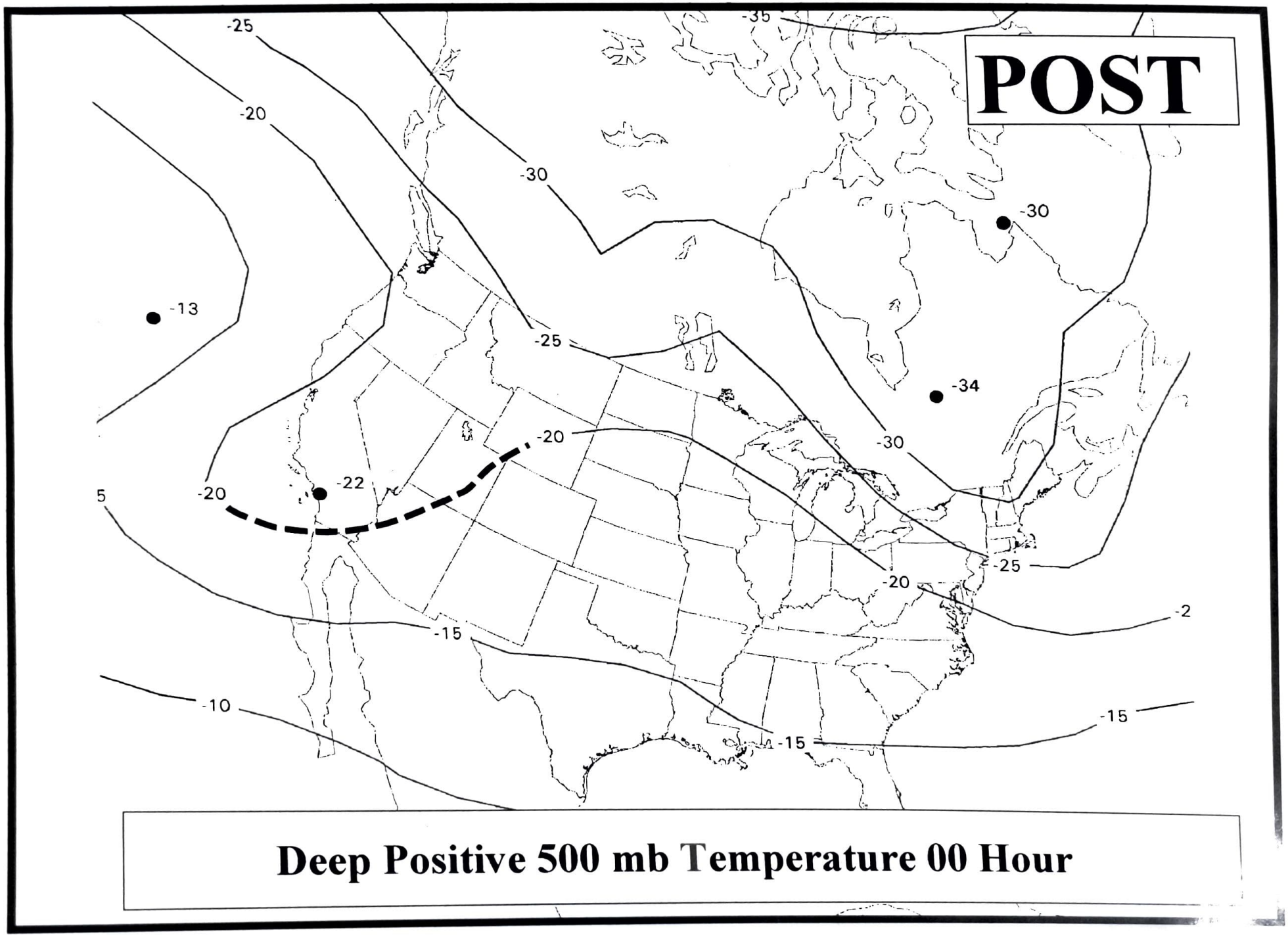
-10
Deep Positive 500 mb Temperature 00 Hour


POST
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-15
-15
Deep Positive 500 mb Temperature 00 Hour

4) DEEP NEGATIVE TILT TROUGH

The Deep Negative pattern produces the highest mean liquid precipitation of the four types. It is important to identify the PRE type because it will almost always will require a Winter Storm Watch/Warning. In both the PRE and POST cases light precipitation often continues after the trough axis has exited Arizona.

Features to monitor when a Deep Negative pattern is developing are:

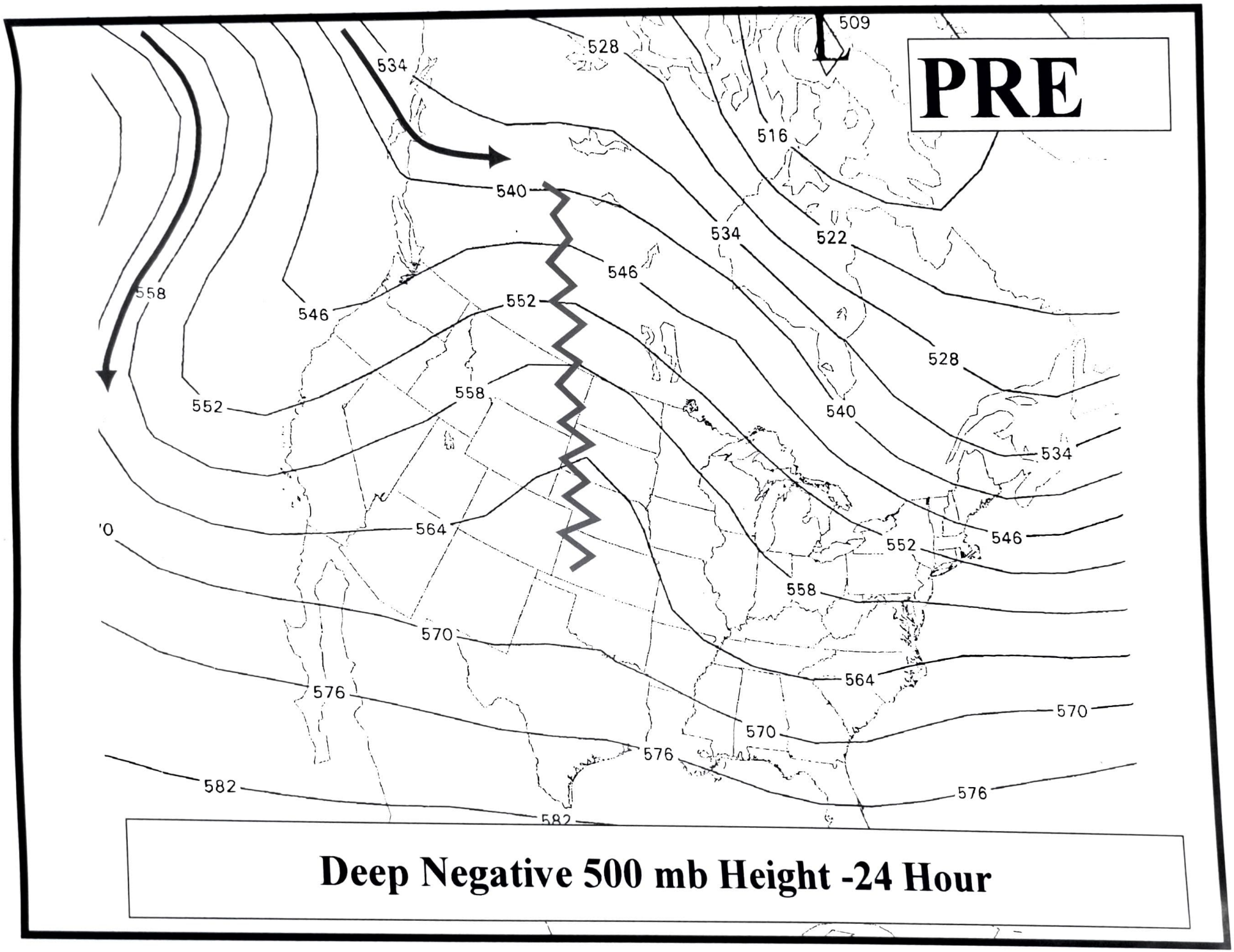
24 hours before the low center has developed over California (see charts):
1) The 500 mb low center in the PRE case is deeper than in the POST case. In addition, the downstream ridge tends to be more over the High Plains in the PRE cases vs. the intermountain west for the POST cases.
2) The jet stream at 250 and 500 mb to the west and south of the developing low is 100 and 60 knots respectively. In the POST case the jet speed is 80 and 40 knot respectively.
3) The nose of the jet is pointing into Arizona in the PRE case. The wind speed gradient at 250 mb across Arizona is north to south at about 30 knots. In the POST cases the gradient is east to west and changes about 10 knots across the state.
4) The -20 degree Celsius isotherm at 500 mb runs across the northwest corner of Arizona in the PRE case where as in the POST case it runs along the northern California and Oregon coasts.

When the low is in California:
1) The jet stream at 250 and 500 mb to the west and south of the low remains 30 to 40 knots stronger than in the POST cases with much more wind speed gradient across northern Arizona.

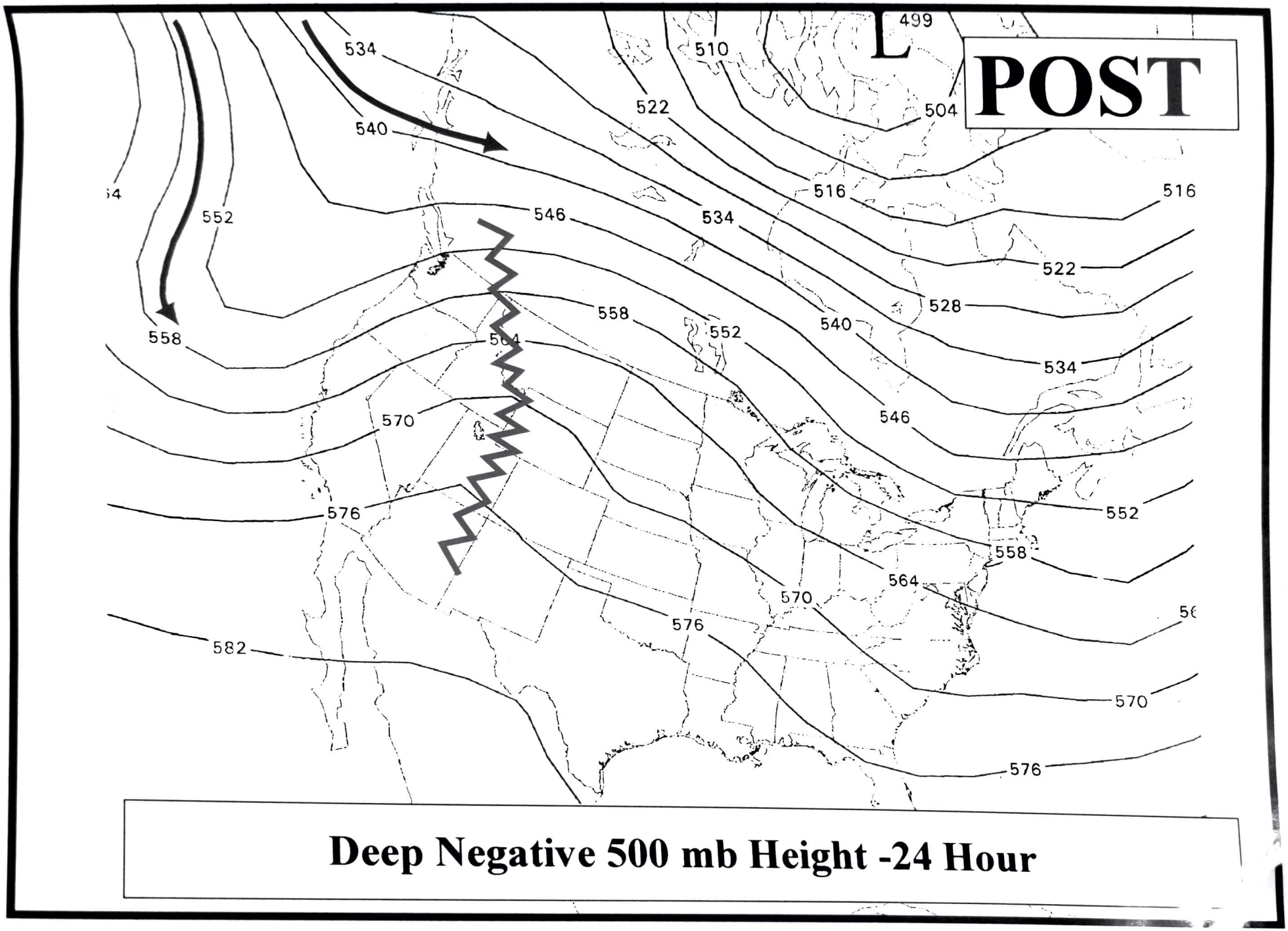
In the Deep Negative case a pre-frontal rainband likely forms as moisture is drawn northward from the subtropics over the Mogollon Rim and into northern Arizona.

The table below shows some of the precipitation statistics at Flagstaff for the Deep Negative events. It can be seen that with the PRE type Deep Negative pattern 30 % of the time precipitation occurred before the low center moved into central and southern portions of California. In the POST case precipitation doesn't start until DAY 2 and is on the light side. The highest POP value for the POST case is 100 percent on DAY 3 while for the PRE case the POP is 100 percent for DAY1 and DAY 2 and 70 percent for DAY 3. In both the PRE and POST case precipitation is possible after the trough axis exits the state.

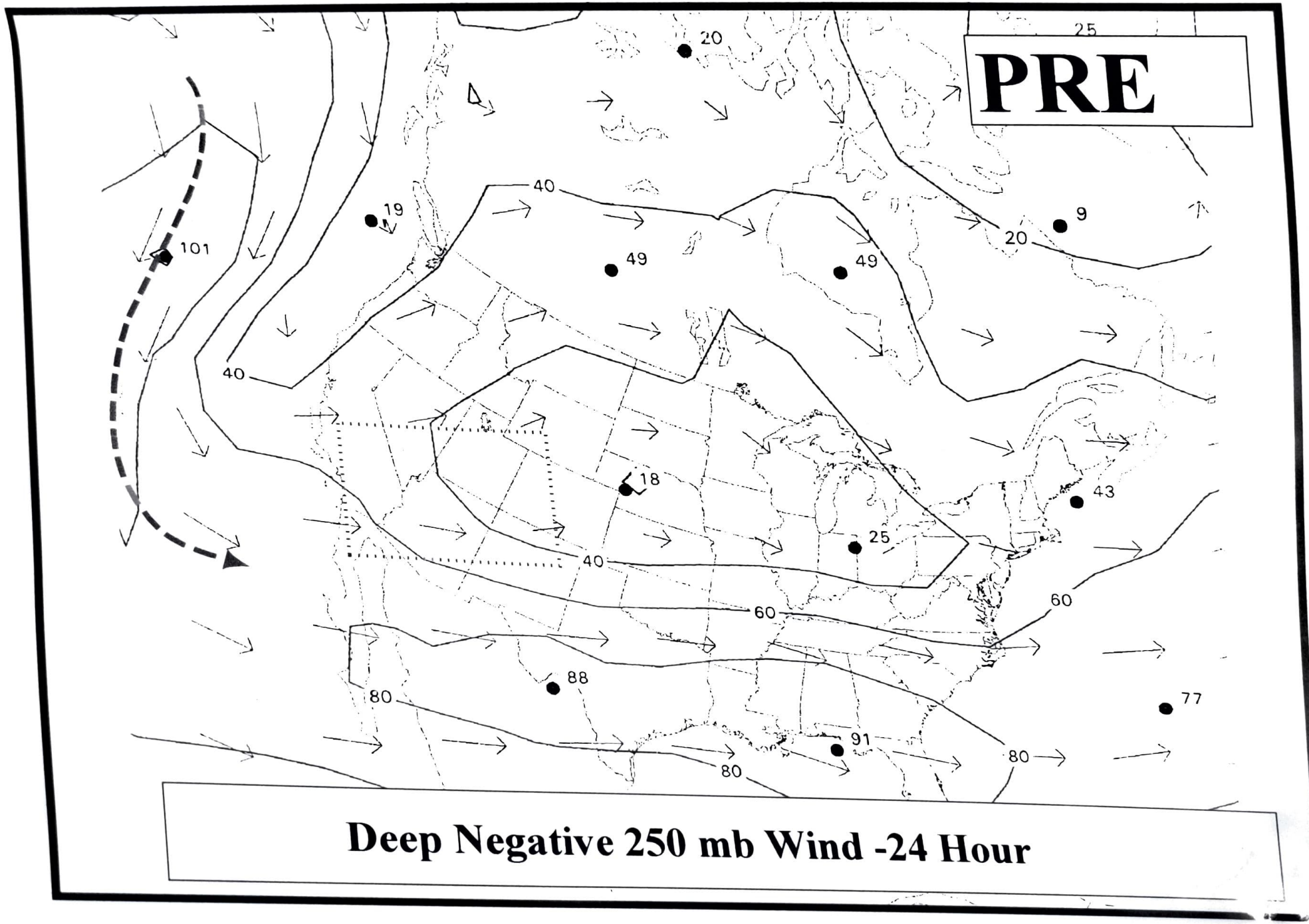
	PRE				**POST**		
	Avg	Range	POP		Avg	Range	POP
Before	0.43	0-.83	30%				
Day 1	0.47	.21-.65	100%				
Day 2	0.37	.02-.71	100%	Day 2	0.13	0-.38	50%
Day 3	0.22	0-.48	67%	Day 3	0.13	.02-.21	100%
Day 4	0.03	0-.03	17%	Day 4	0.30	0-.6	50%
After	0.02	0-.03	17%	After	0.92	0-1.92	75%



Deep Negative 500 mb Height -24 Hour



Deep Negative 500 mb Height -24 Hour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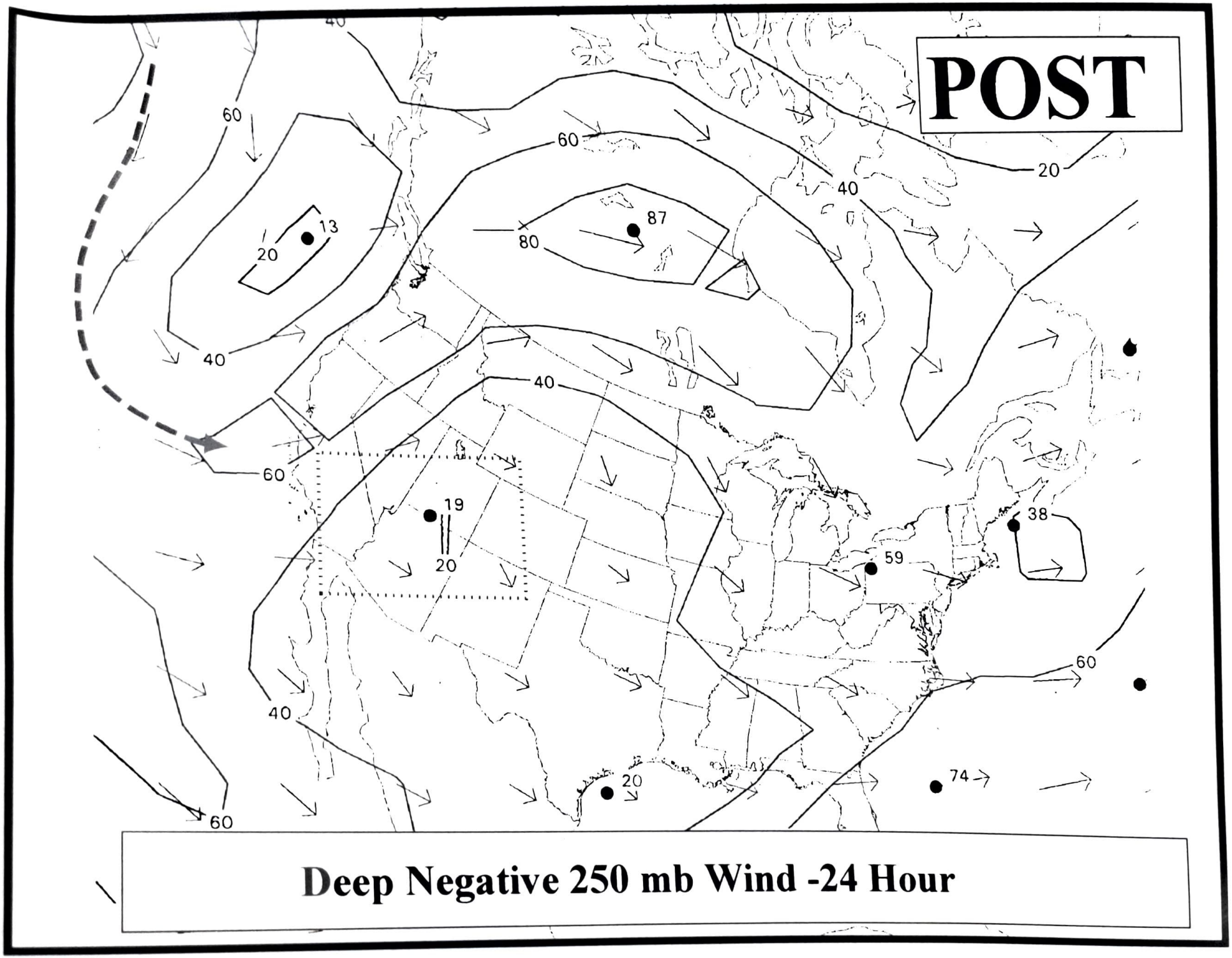
Deep Negative 250 mb Wind -24 Hour


POST
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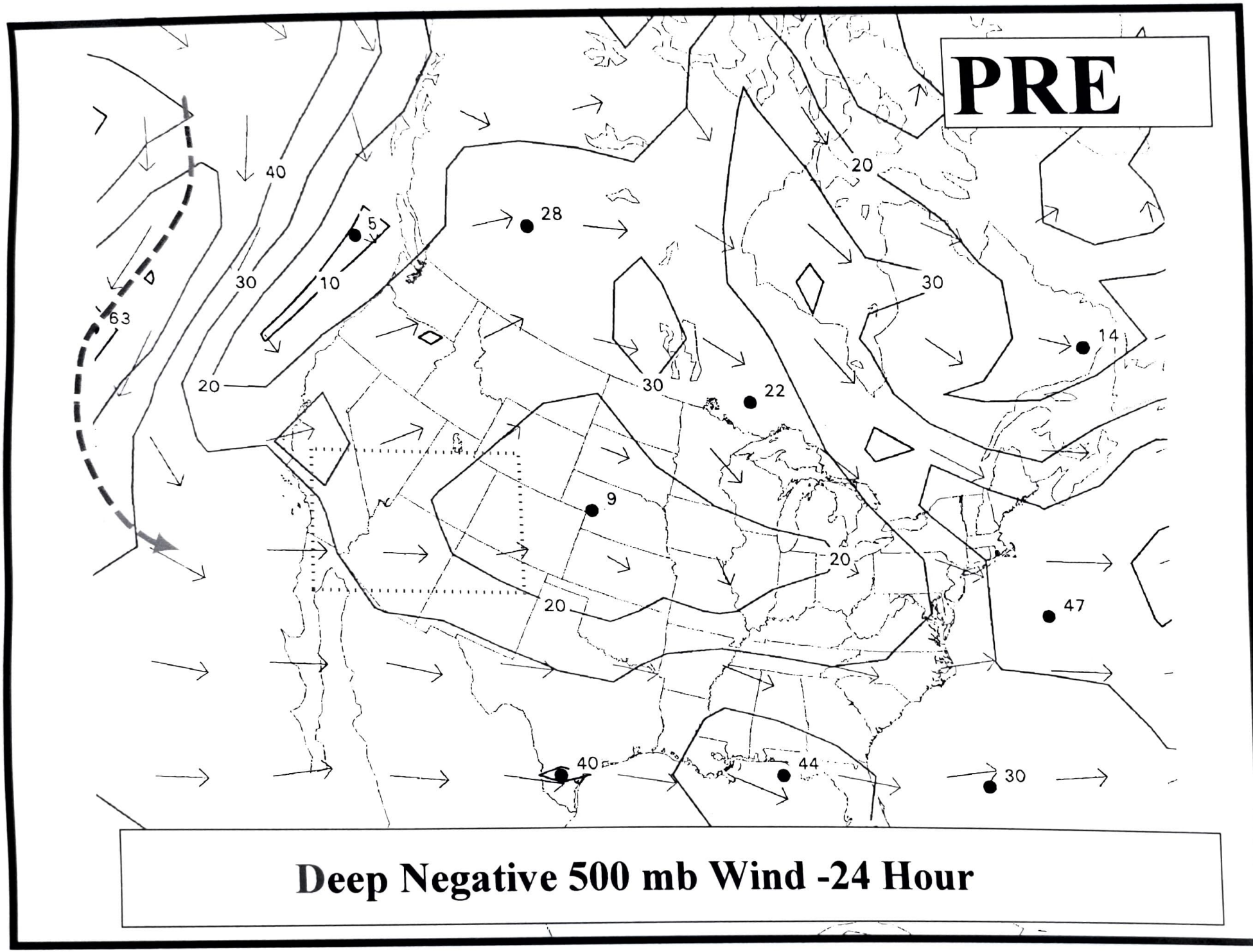
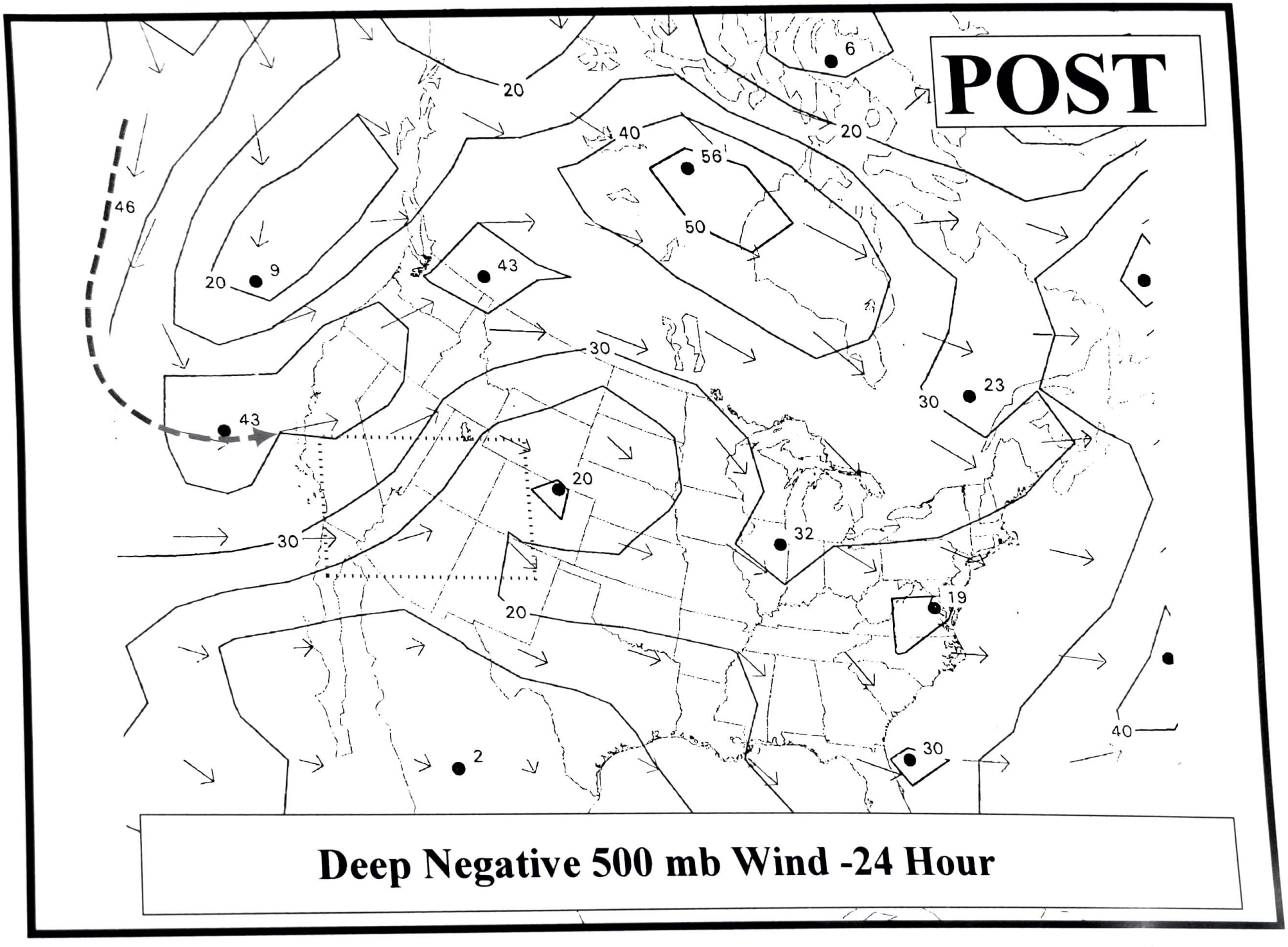
Deep Negative 250 mb Wind -24 Hour



Deep Negative 500 mb Wind -24 Hour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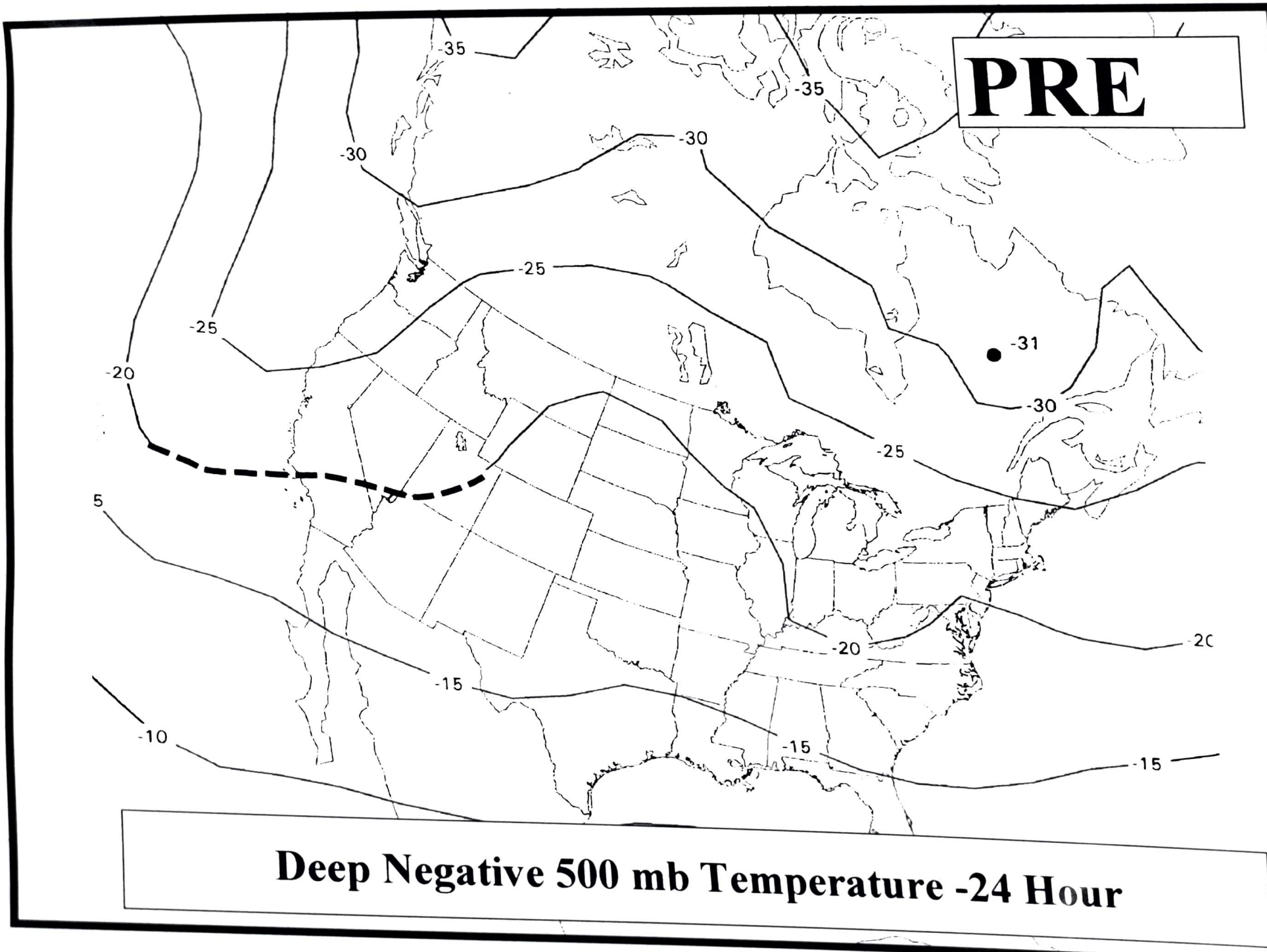
Deep Negative 500 mb Wind -24 Hour


PRE
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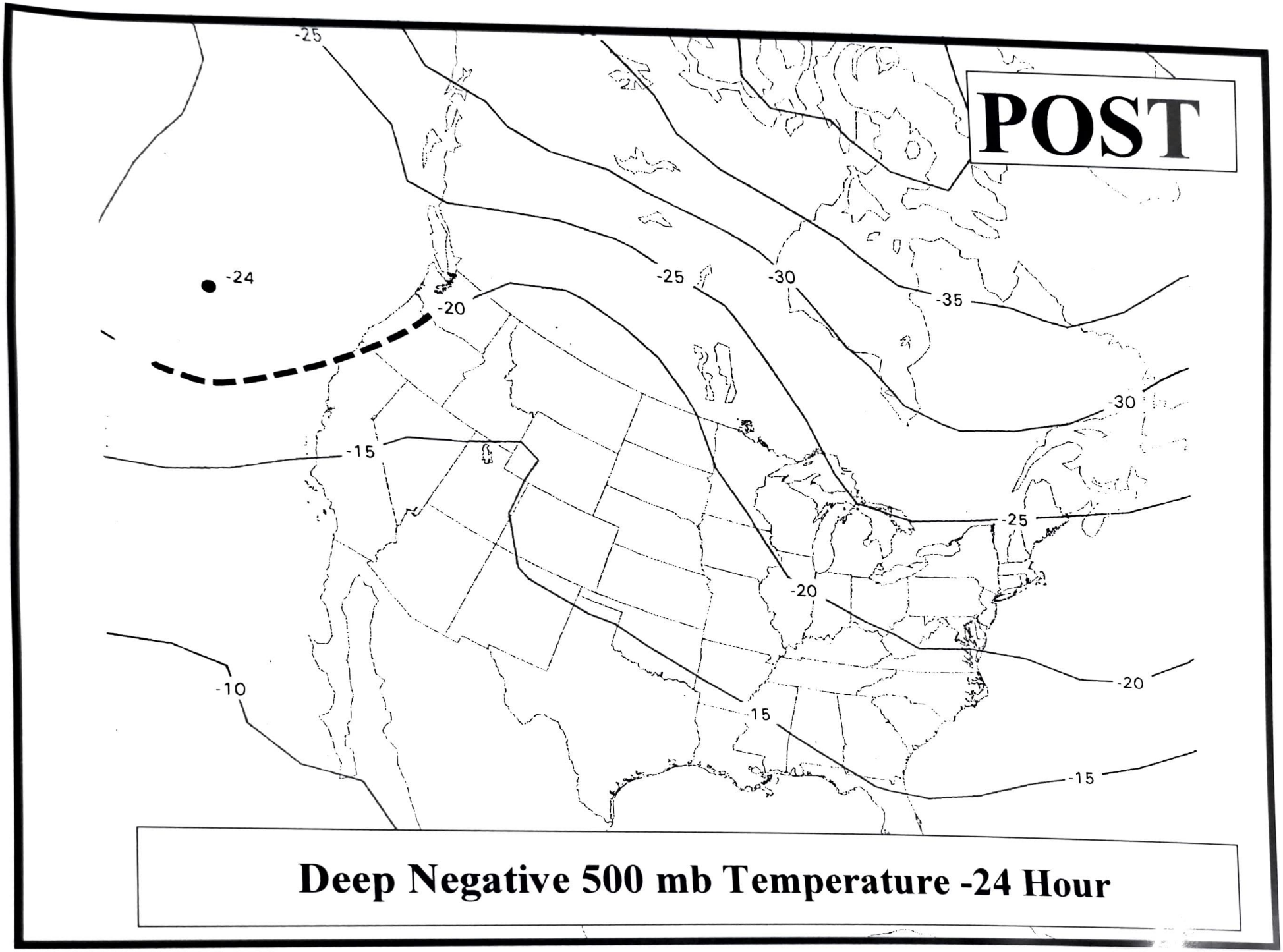
-15
Deep Negative 500 mb Temperature -24 Hour


POST
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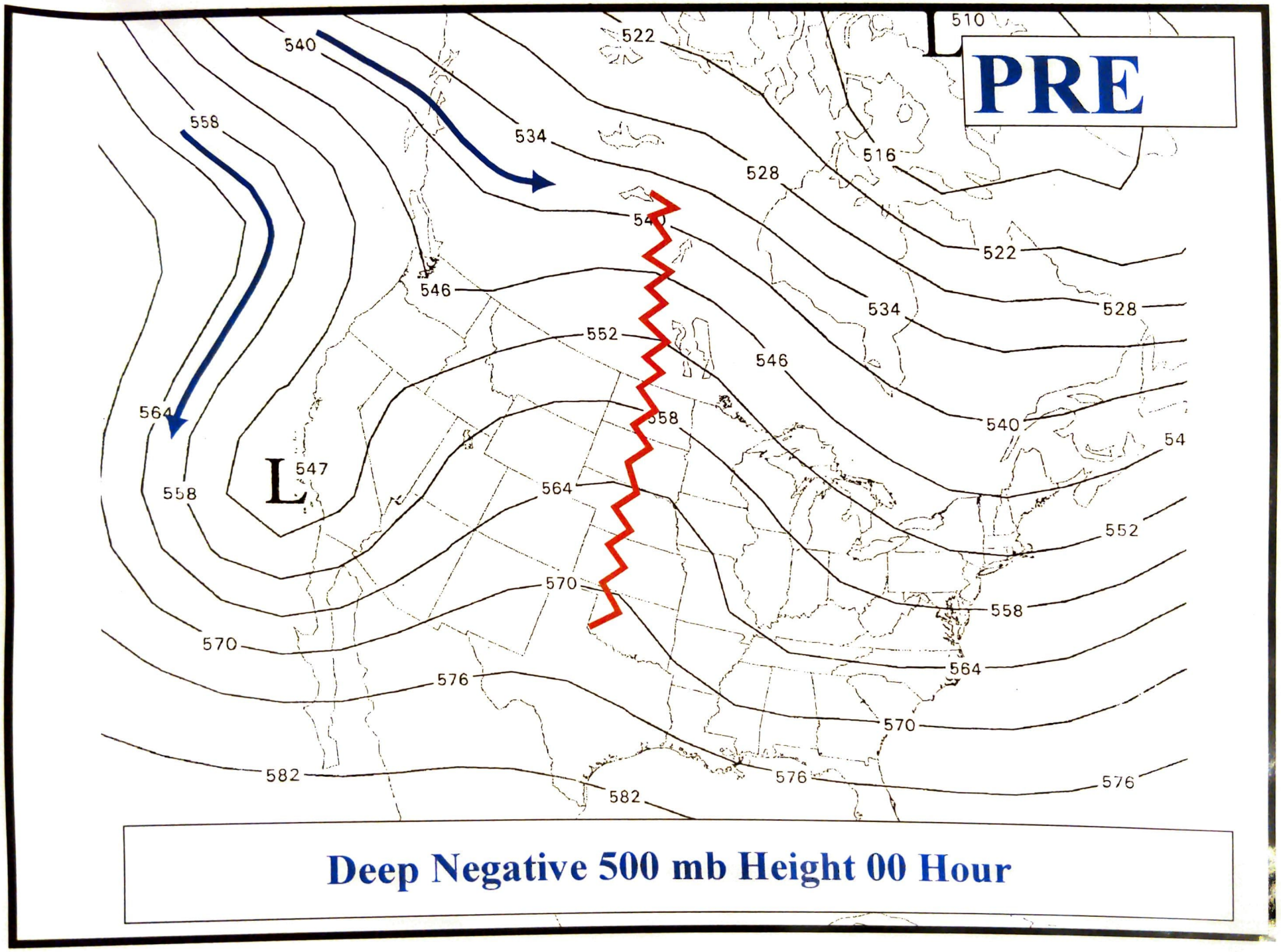
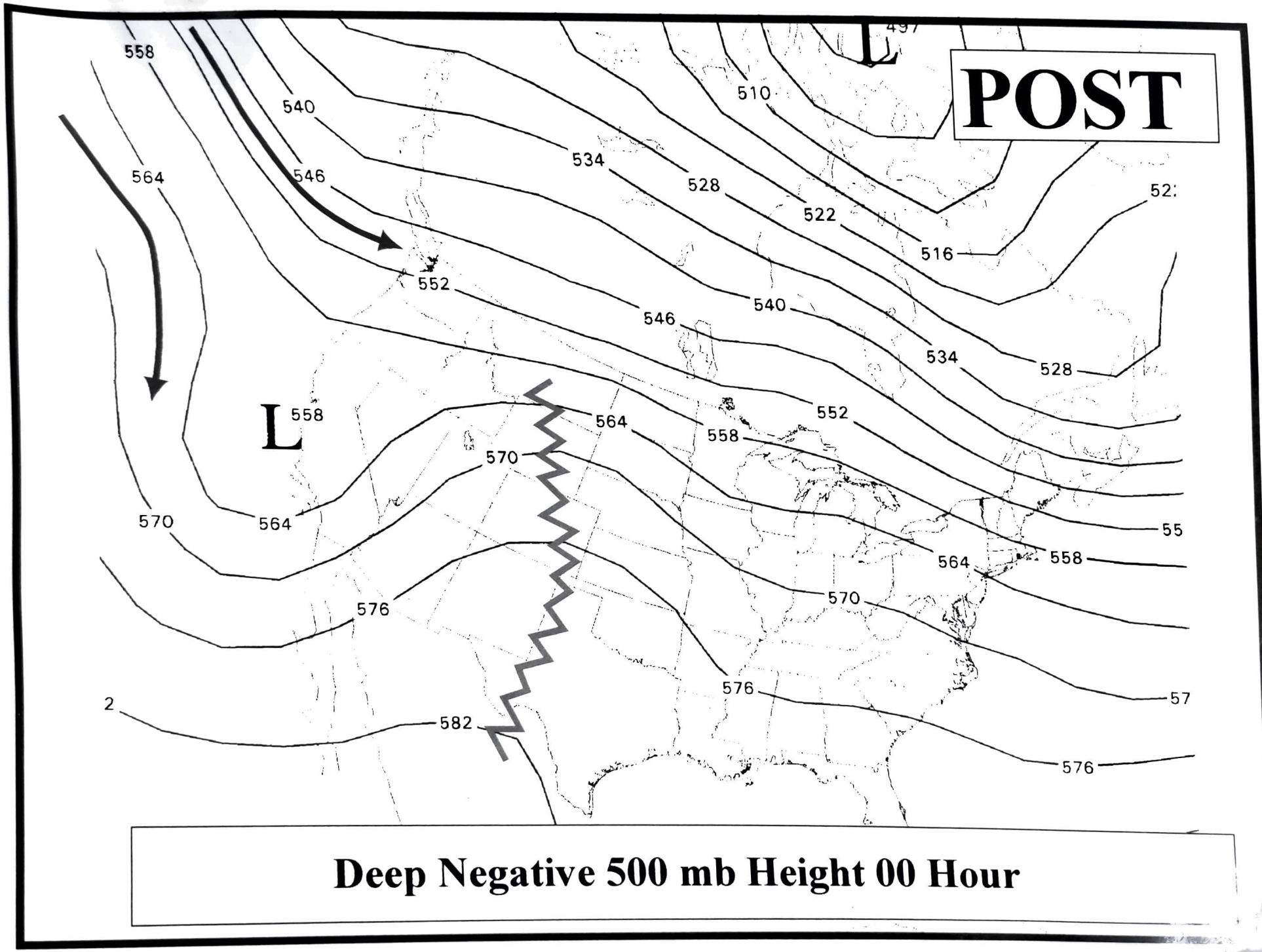
Deep Negative 500 mb Temperature -24 Hour



Deep Negative 500 mb Height 00 Hour


POST
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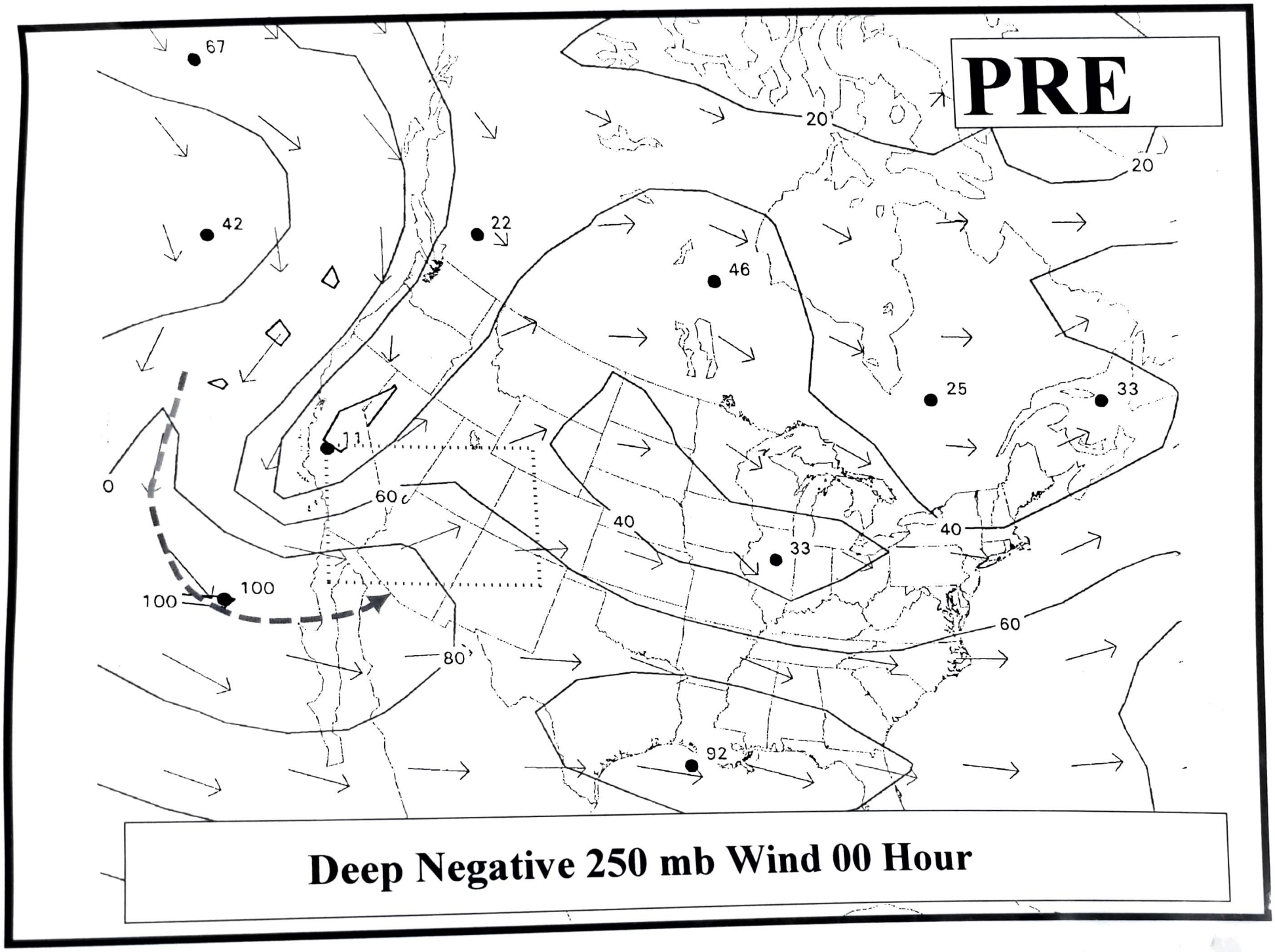
Deep Negative 500 mb Height 00 Hour


PRE
67
42
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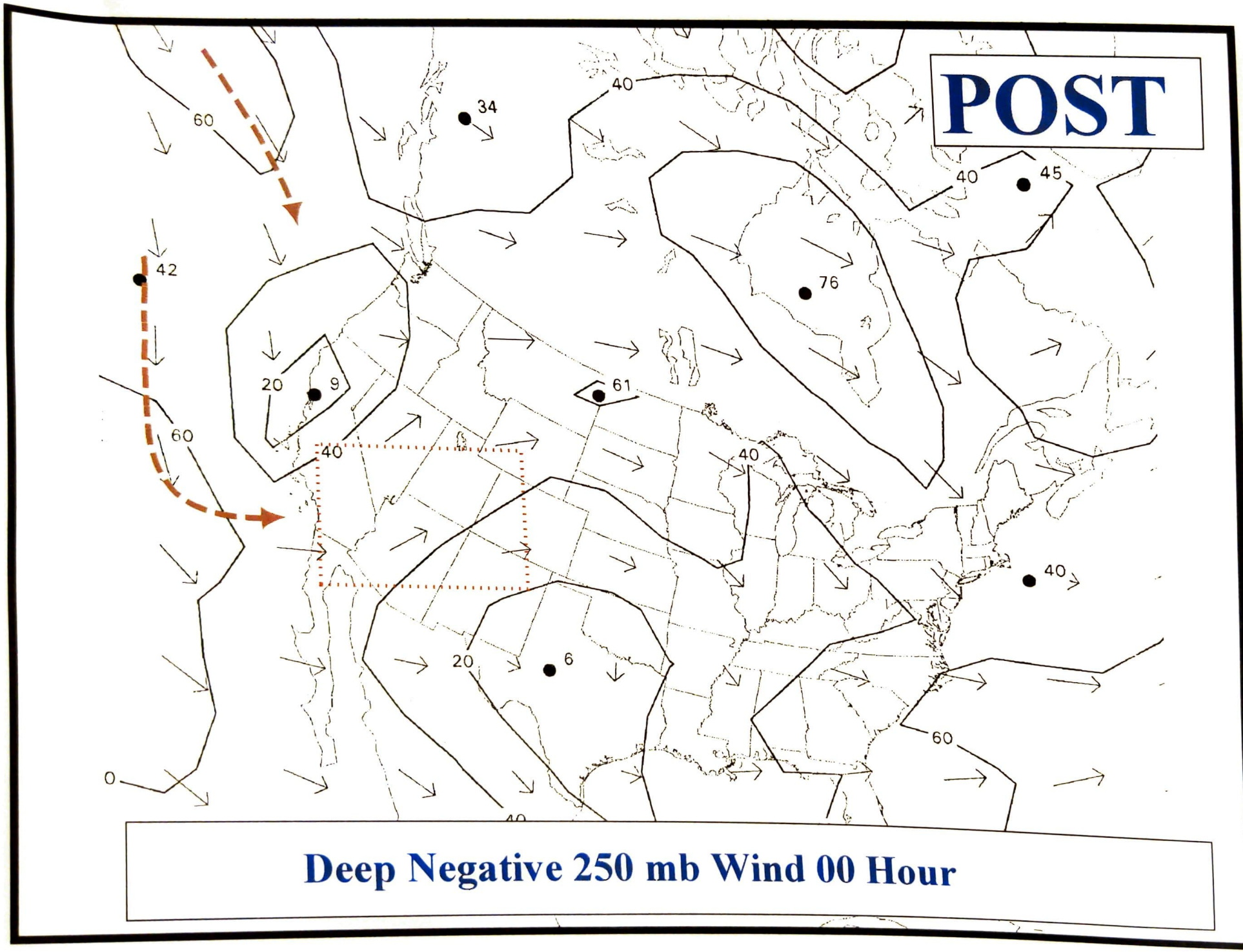
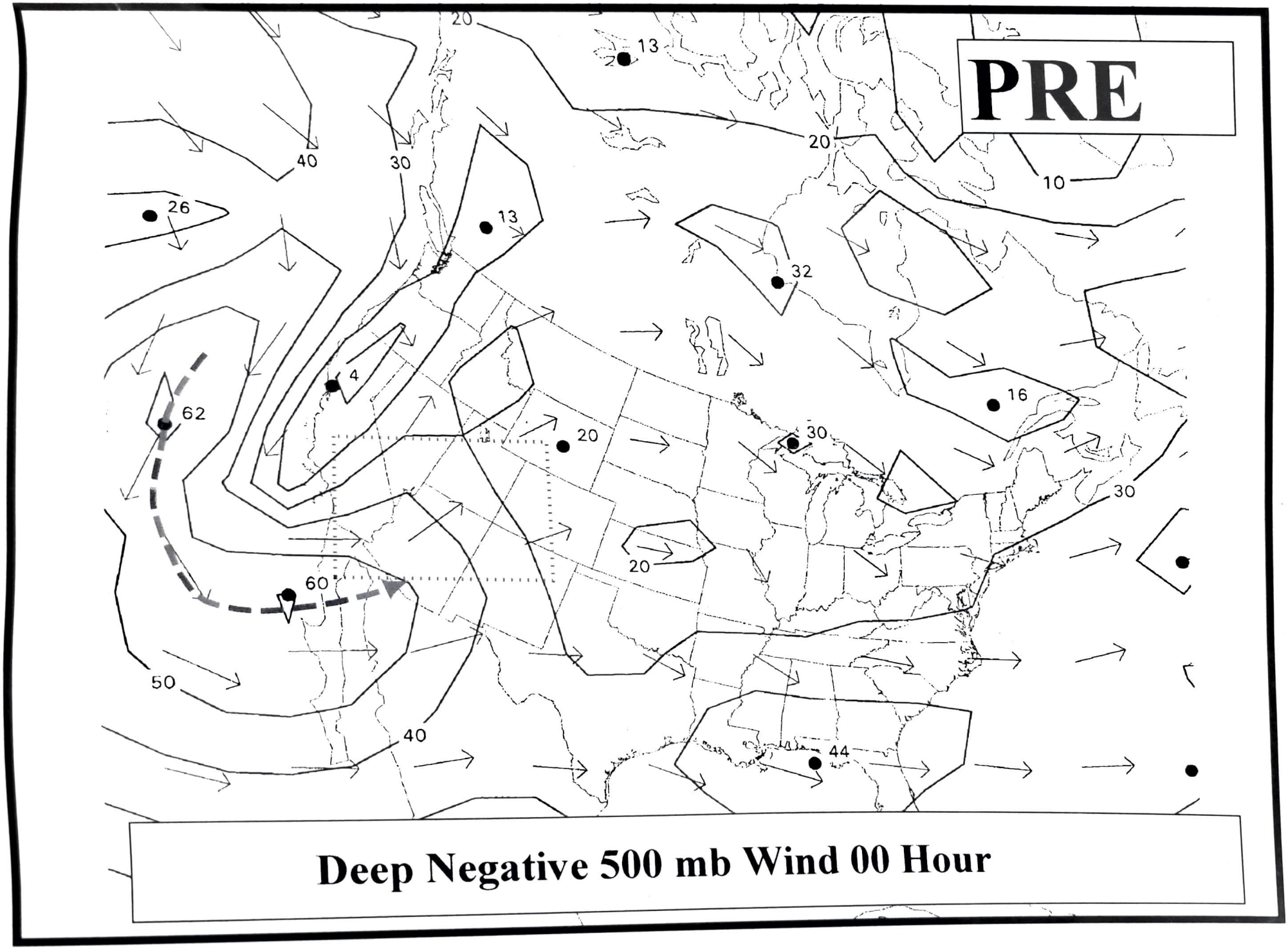
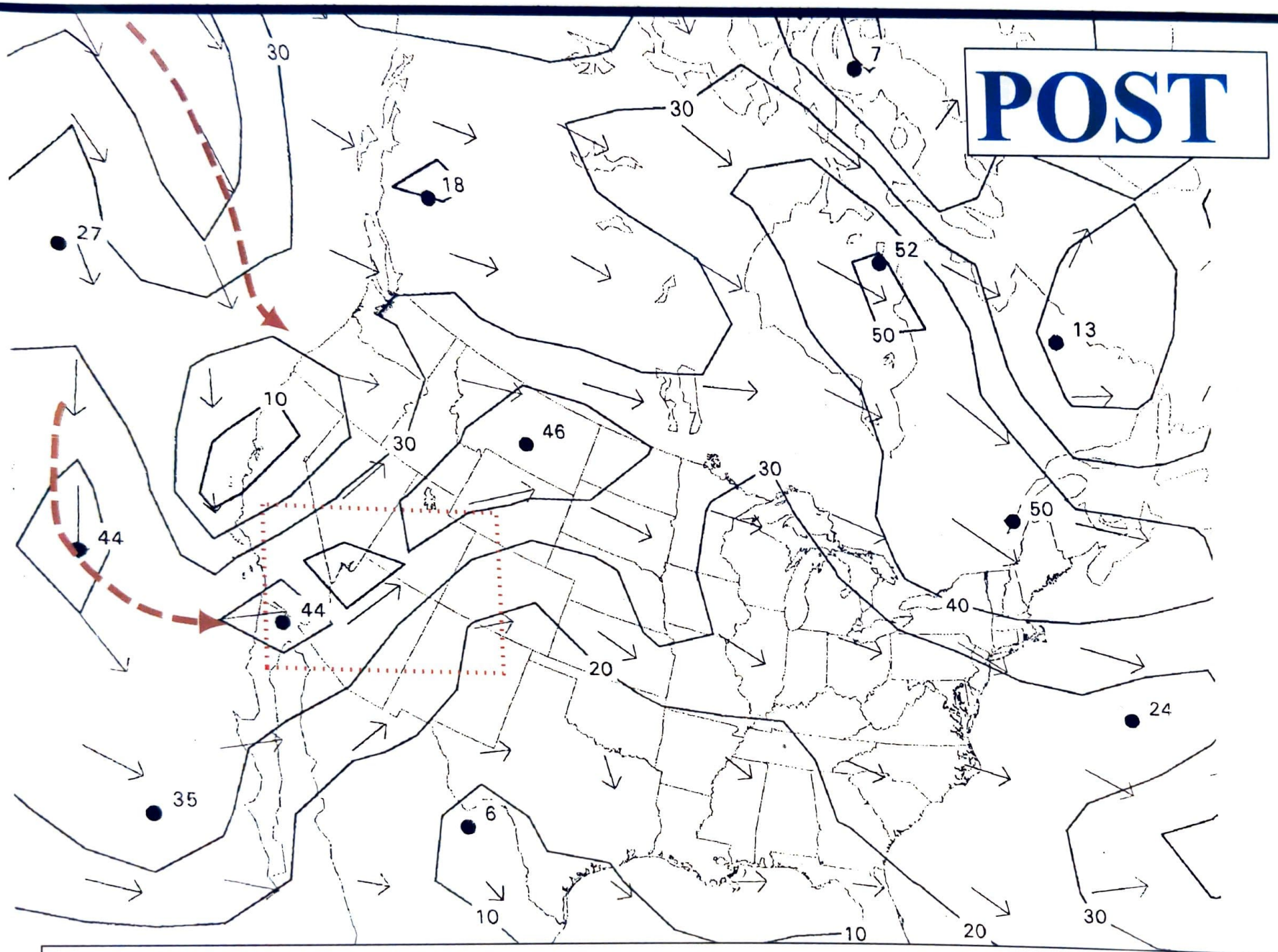
Deep Negative 250 mb Wind 00 Hour



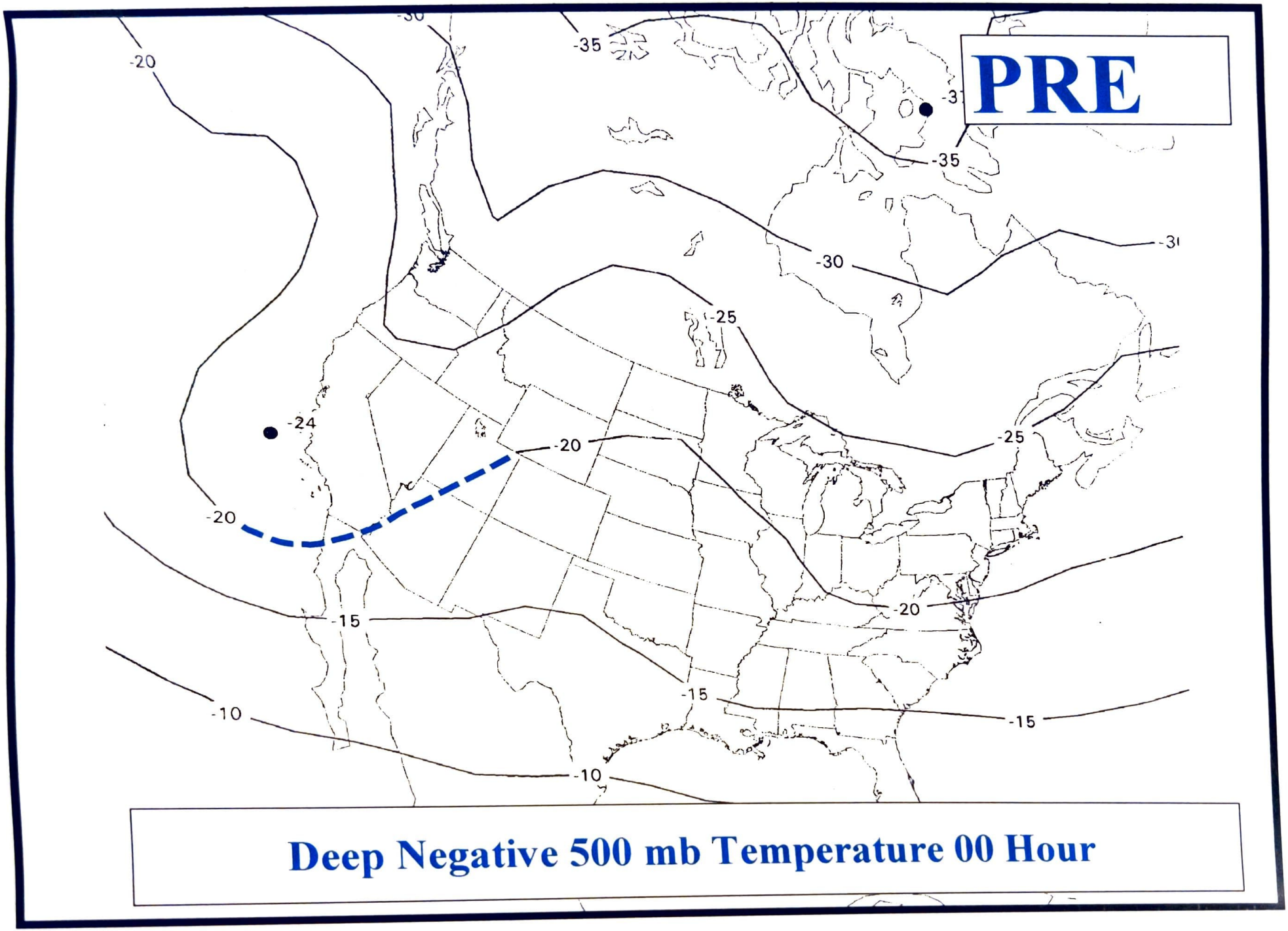
Deep Negative 250 mb Wind 00 Hour



Deep Negative 500 mb Wind 00 Hour



Deep Negative 500 mb Wind 00 Hour


PRE
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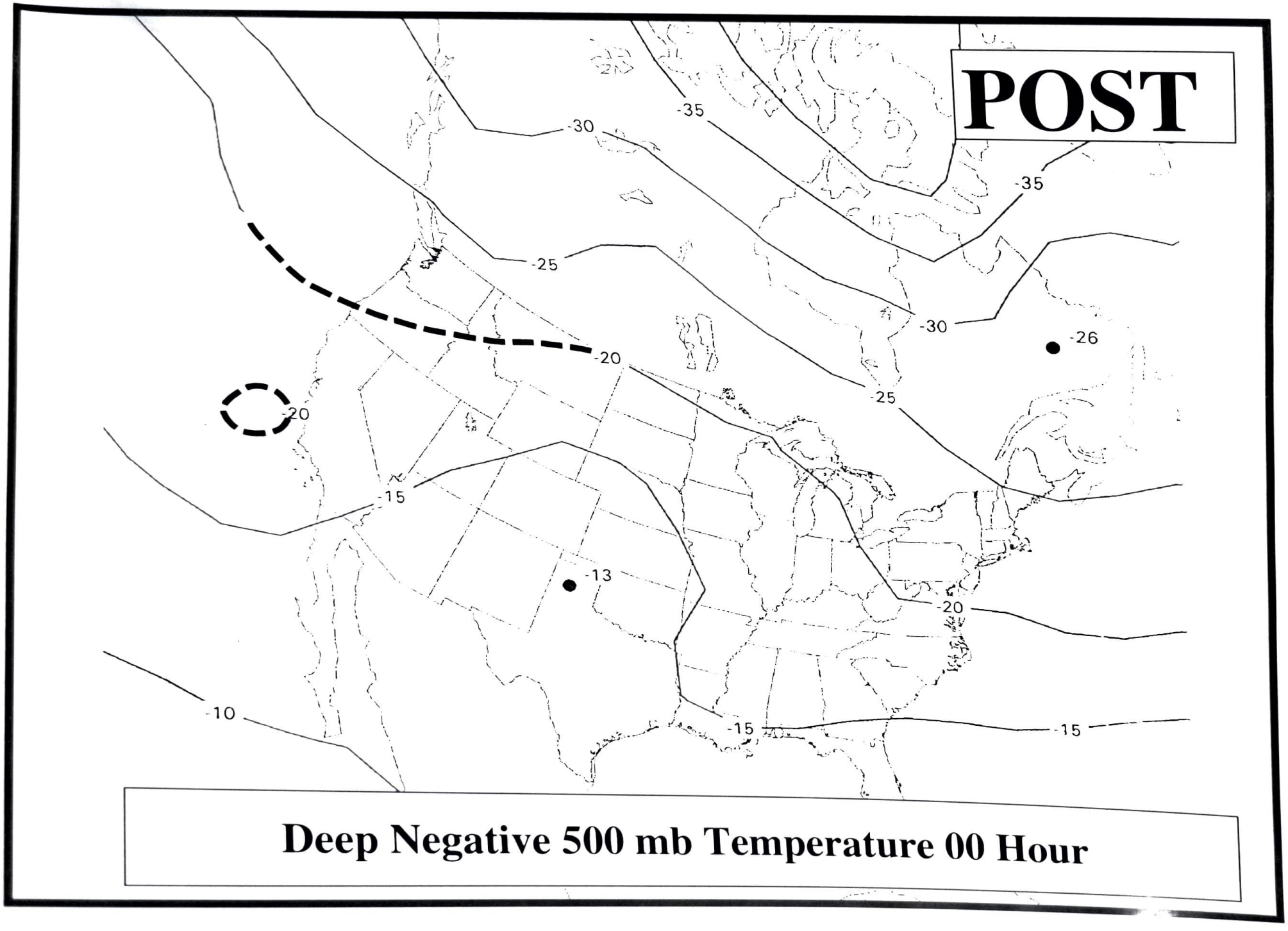
Deep Negative 500 mb Temperature 00 Hour



Deep Negative 500 mb Temperature 00 Hour

5) SPLIT FLOW

The Split Flow pattern produces the second lowest mean liquid precipitation of the four types. It is important to identify the cases where the early onset of precipitation occurs (PRE case) since a snow advisory will likely be required. Light precipitation often continues after the trough axis has exited Arizona.

Features to monitor when a Split Flow pattern is developing are:

24 hours before the low center has developed over California (see charts):
1) 24 hours in advance, the 500 mb low centers are similar. The main difference is that in the PRE case the downstream ridge axis is more prominent (almost) forming a block with a strong short wave diving into the mid west. In the POST case the upstream ridging is more prominent.
2) In the PRE cases the jet stream at 250 and 500 mb to the west of the developing low is 70 and 50 knots respectively. In the POST cases the 250 and 500 mb jet speeds are 50 and 20 knots respectively (much weaker).
3) In the PRE cases the wind speed gradient is about 40 knots across northern Arizona where in the POST cases it is only 10 knots.

When the low is in California:
1) The jet stream (in the PRE cases) at 250 and 500 mb to the west of the low remains 20 to 40 knots stronger than in the POST case with the nose of the jet pointing into southern Arizona.

Similar to the Deep Negative case, a pre-frontal rainband likely forms as moisture is drawn northward from the subtropics orthogonal to the Mogollon Rim and into northern Arizona..

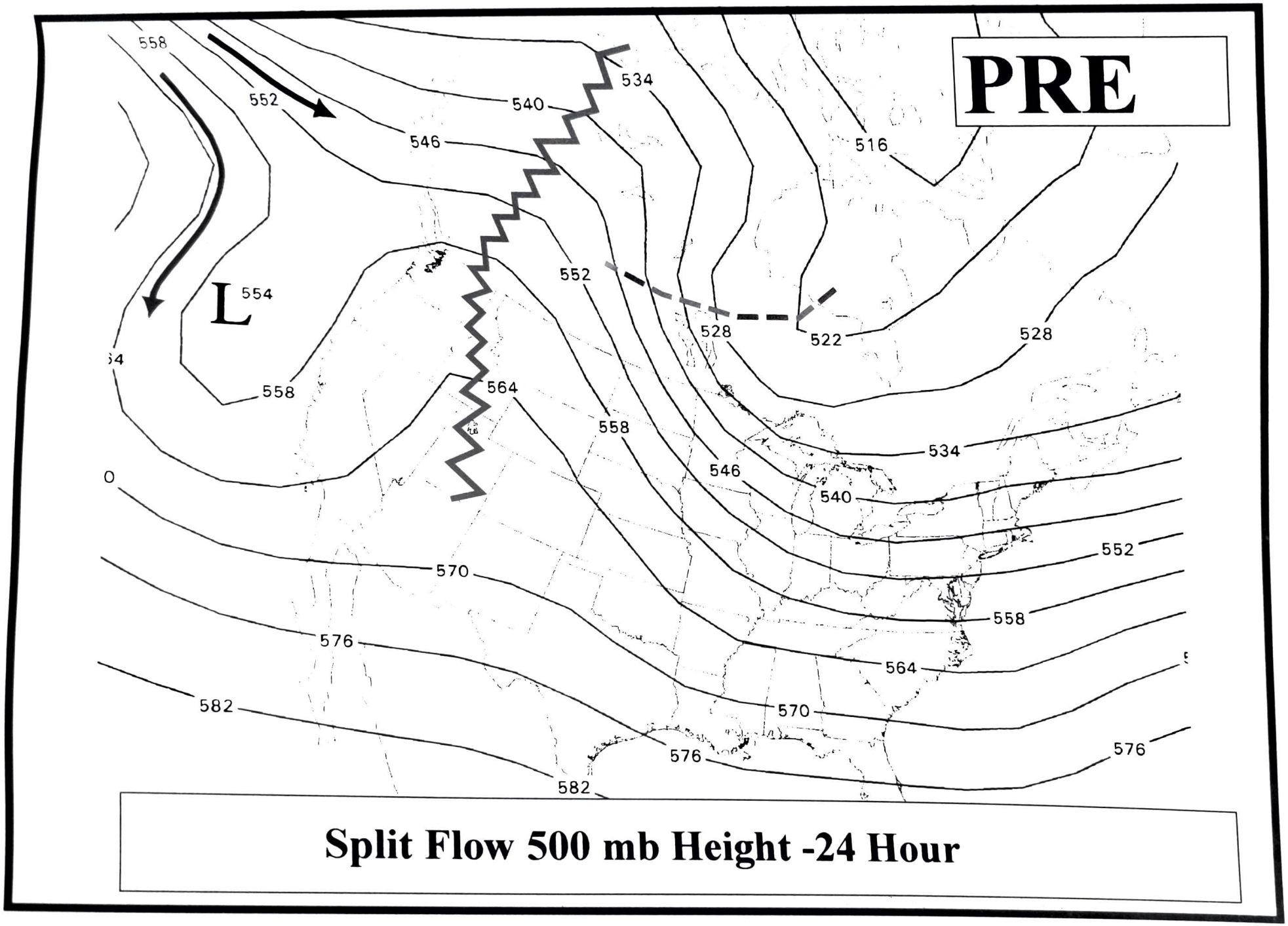
The table below shows some of the precipitation statistics at Flagstaff for the Split Flow events. It can be seen that in the PRE type Split Flow pattern, precipitation occurred before the low center moved into central and southern portions of California nearly 70 % of the time. In the POST case, precipitation doesn't start until DAY 2 and is usually on the light side. The highest POP value for the POST case is 50 percent for any given period while for the PRE case the POP is near 100 percent for DAY1 and DAY 2. In both the PRE and POST case, precipitation is possible after the trough axis exits the state. This is probably the result of residual moisture interacting with a secondary short wave.

PRE

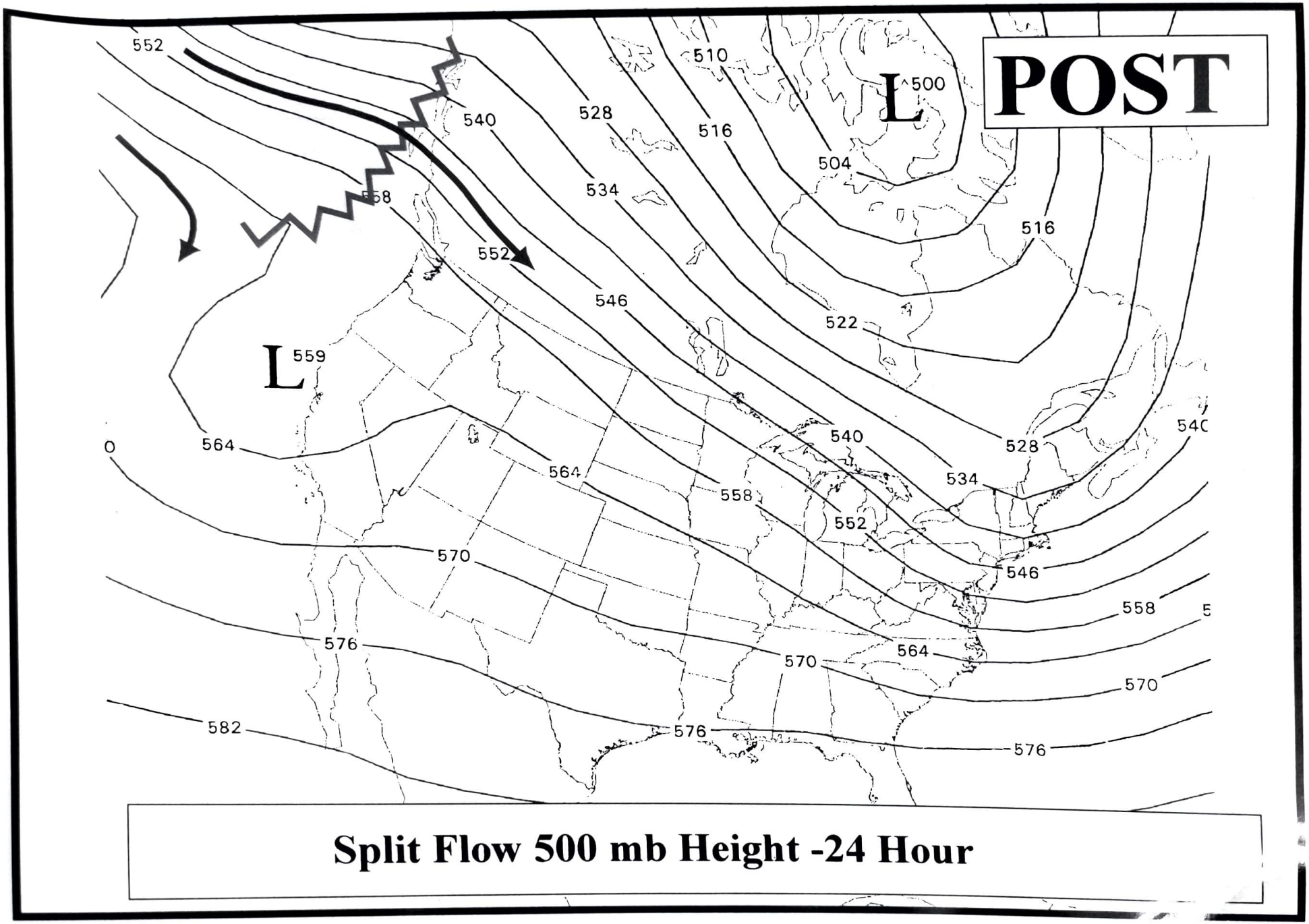
	Avg	Range	POP
Before	0.32	0-1.04	67%
Day 1	0.28	.09-.79	100%
Day 2	0.27	0-.53	80%
Day 3	0.22	0-.40	50%
Day 4	0.48	0-.95	17%
Day 5	0.04	0-.07	17%
After	0.42	0-.79	33%

POST

	Avg	Range	POP
Day 2	0.13	0-.37	50%
Day 3	0.10	0-43	50%
Day 4	0.01	0-.02	40%
After	0.27	0-.58	40%



Split Flow 500 mb Height -24 Hour


POST
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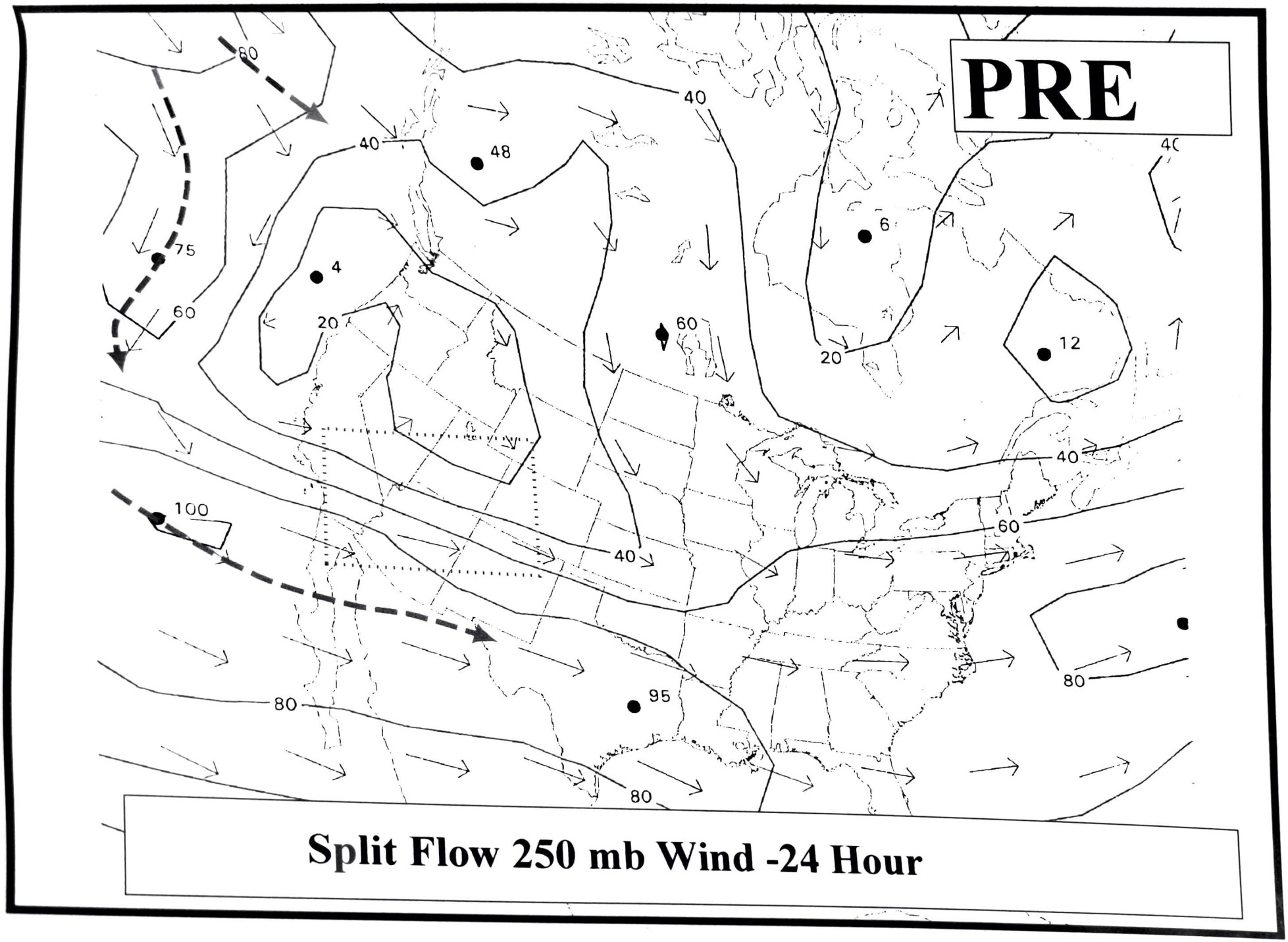
Split Flow 500 mb Height -24 Hour


PRE
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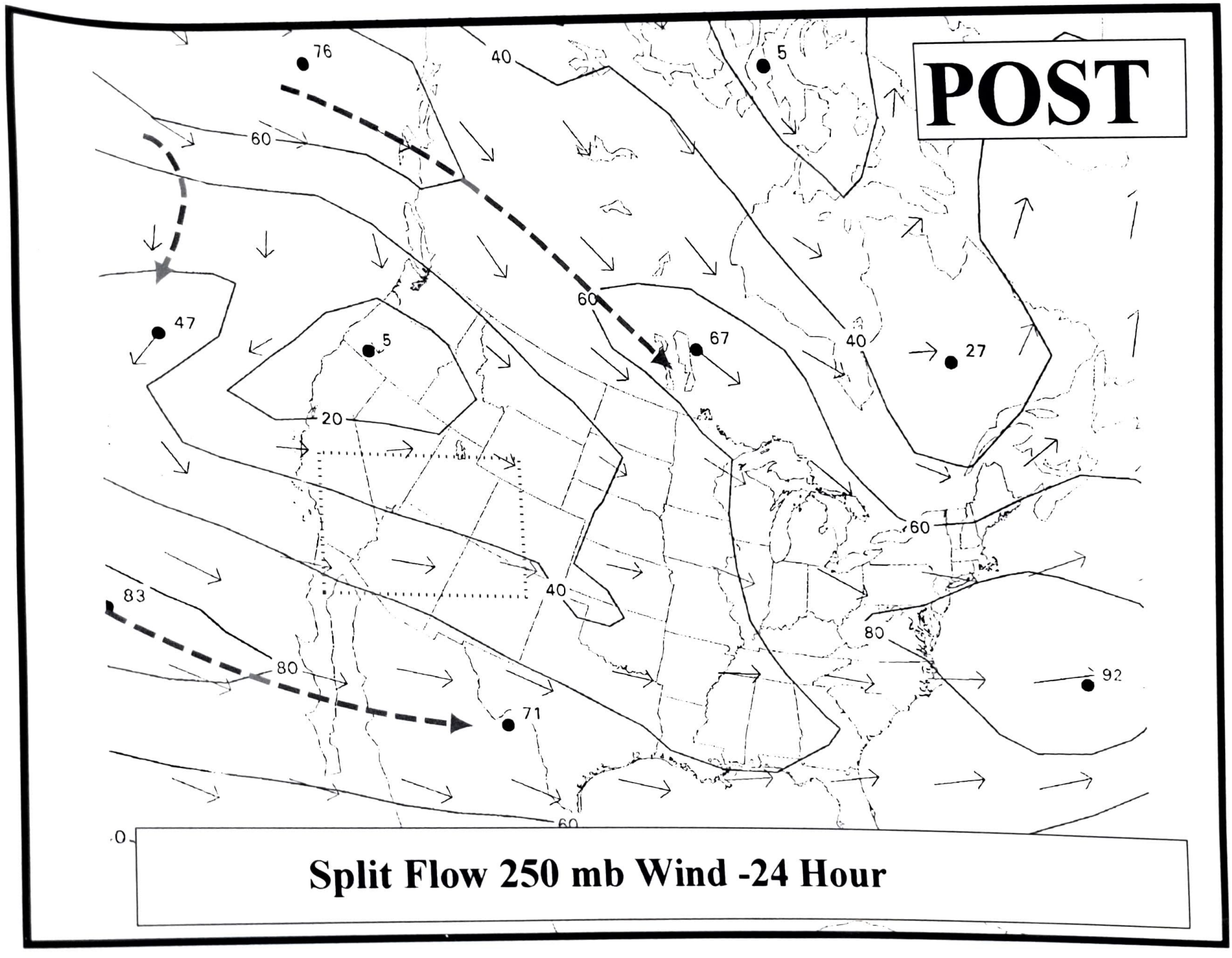
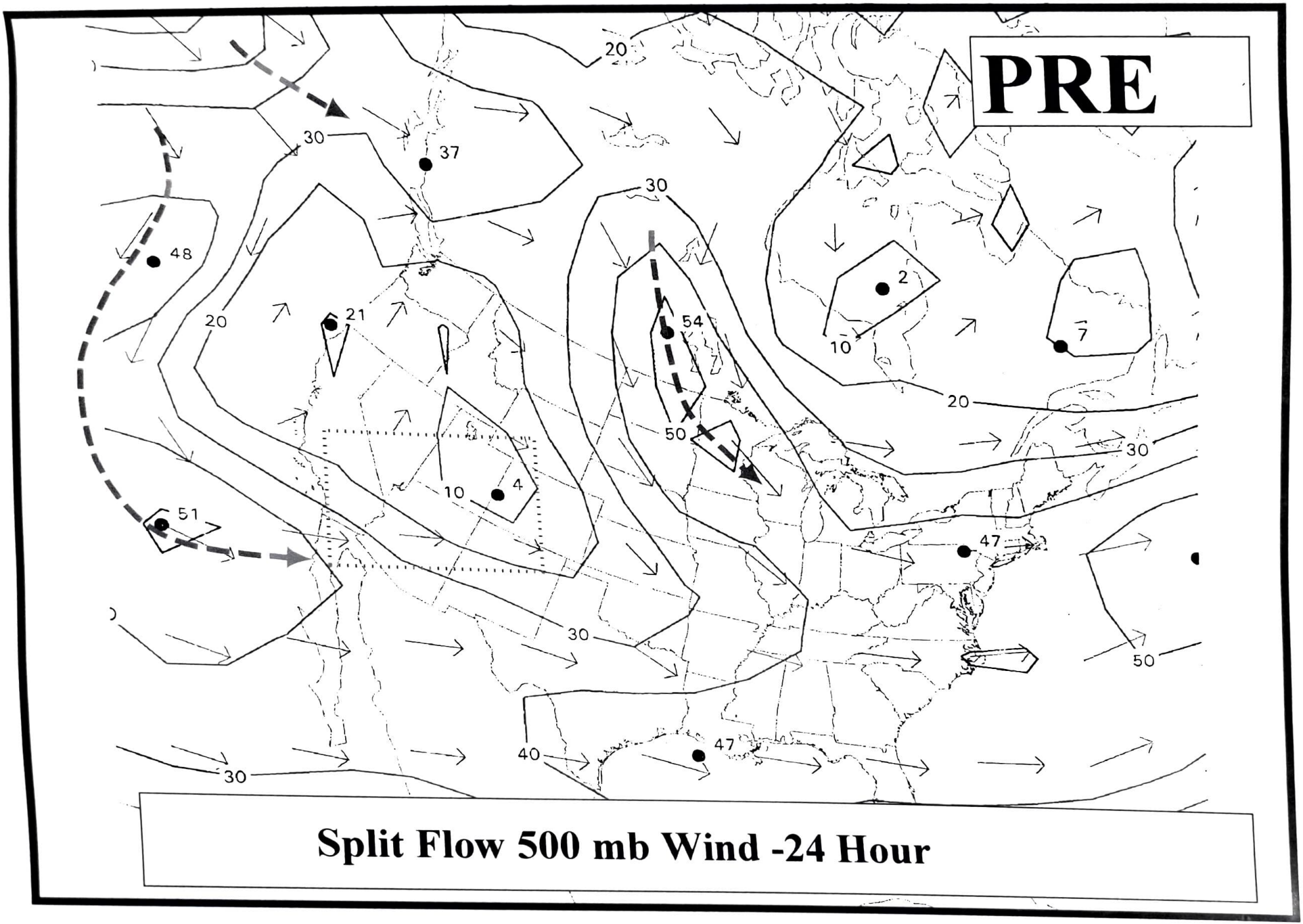
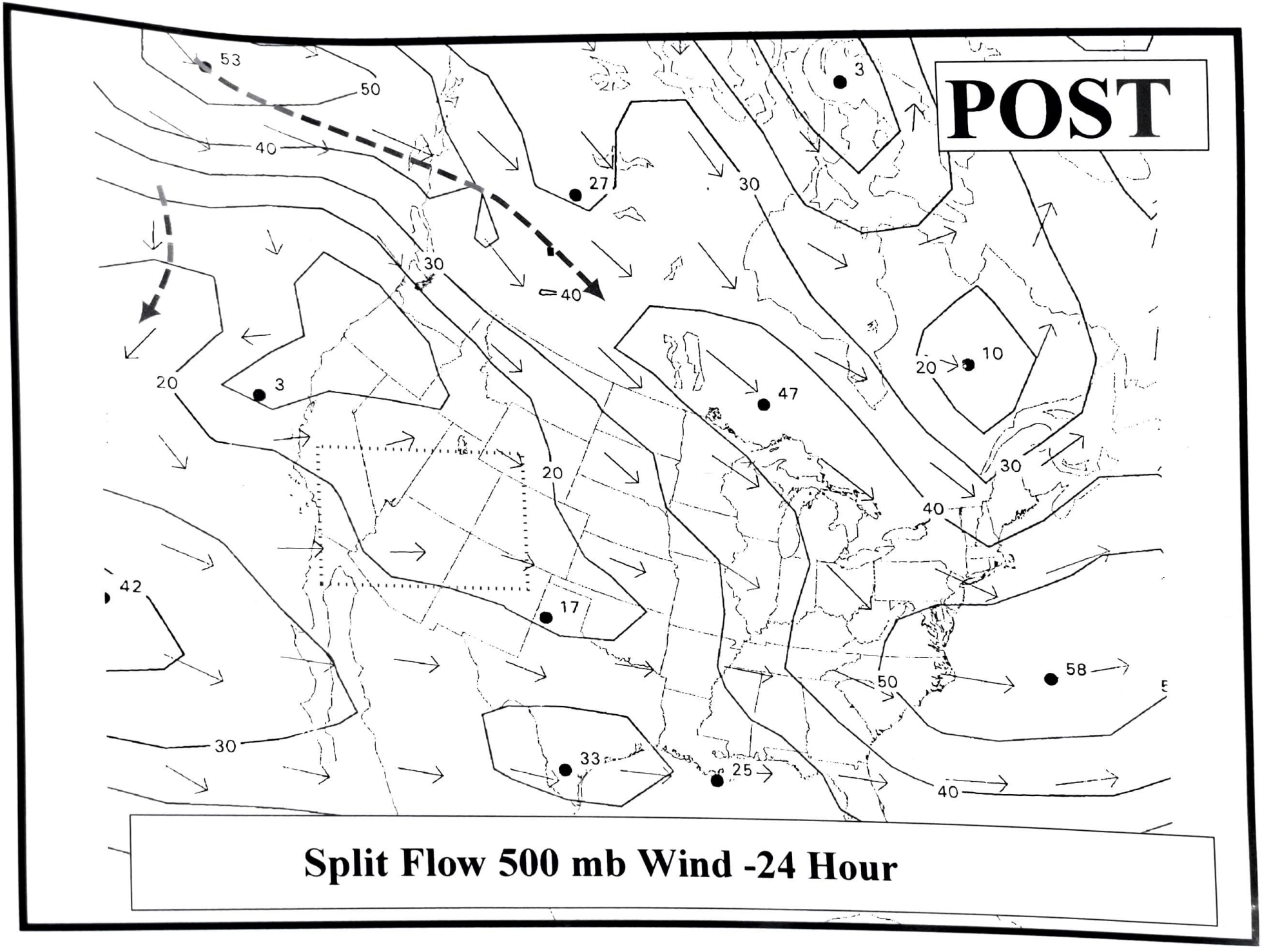
Split Flow 250 mb Wind -24 Hour



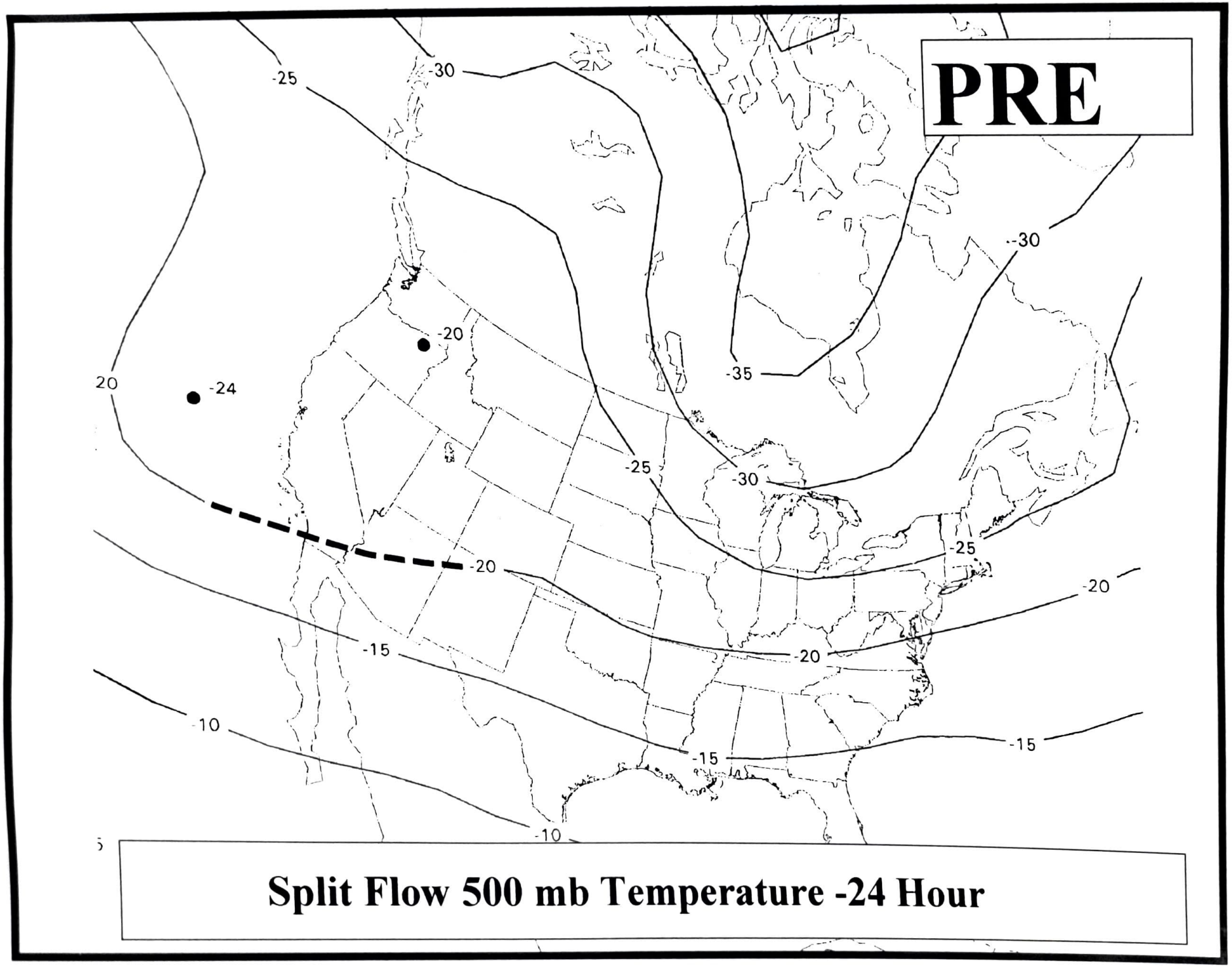
Split Flow 250 mb Wind -24 Hour



Split Flow 500 mb Wind -24 Hour



Split Flow 500 mb Wind -24 Hour


PRE
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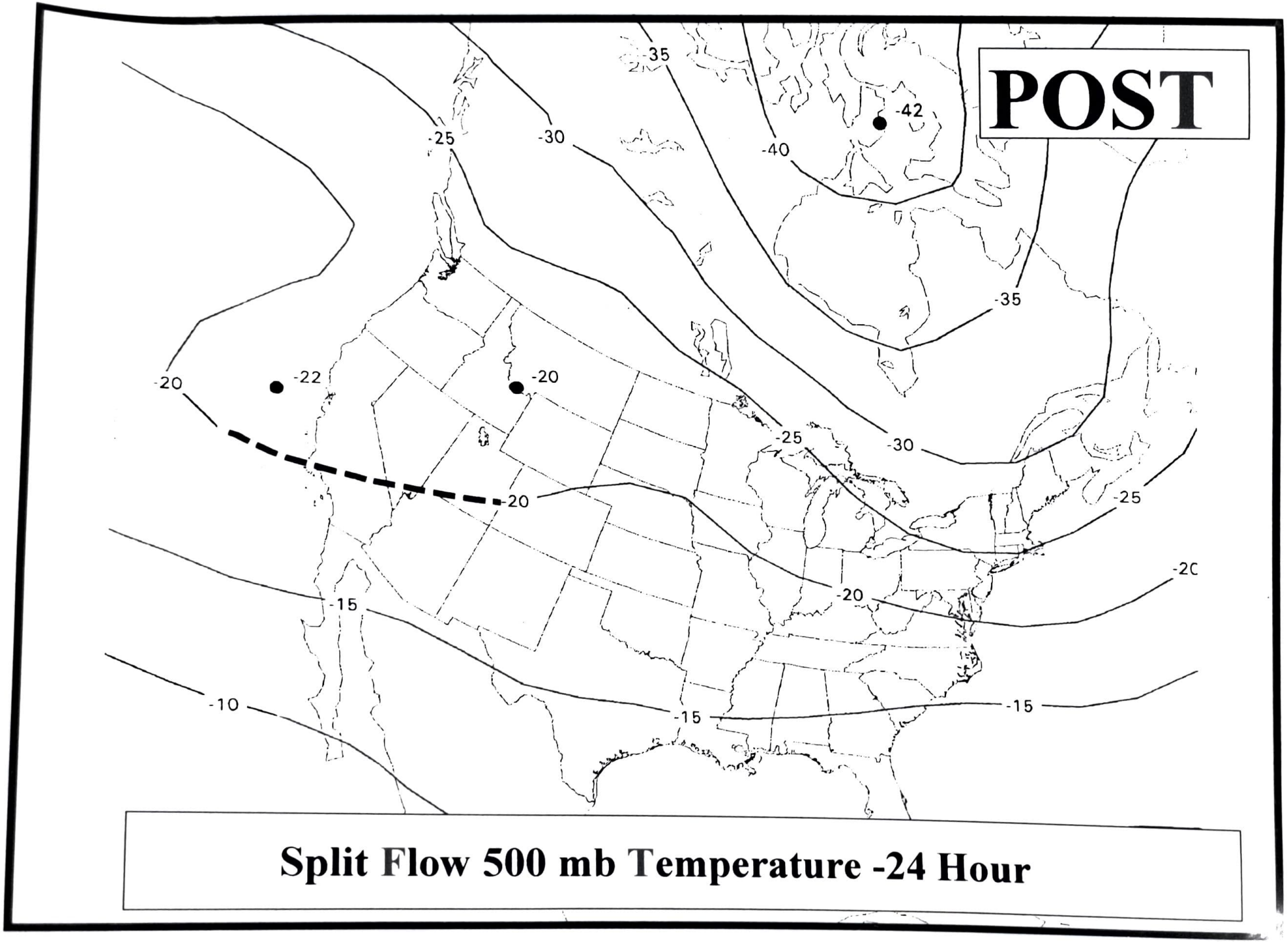
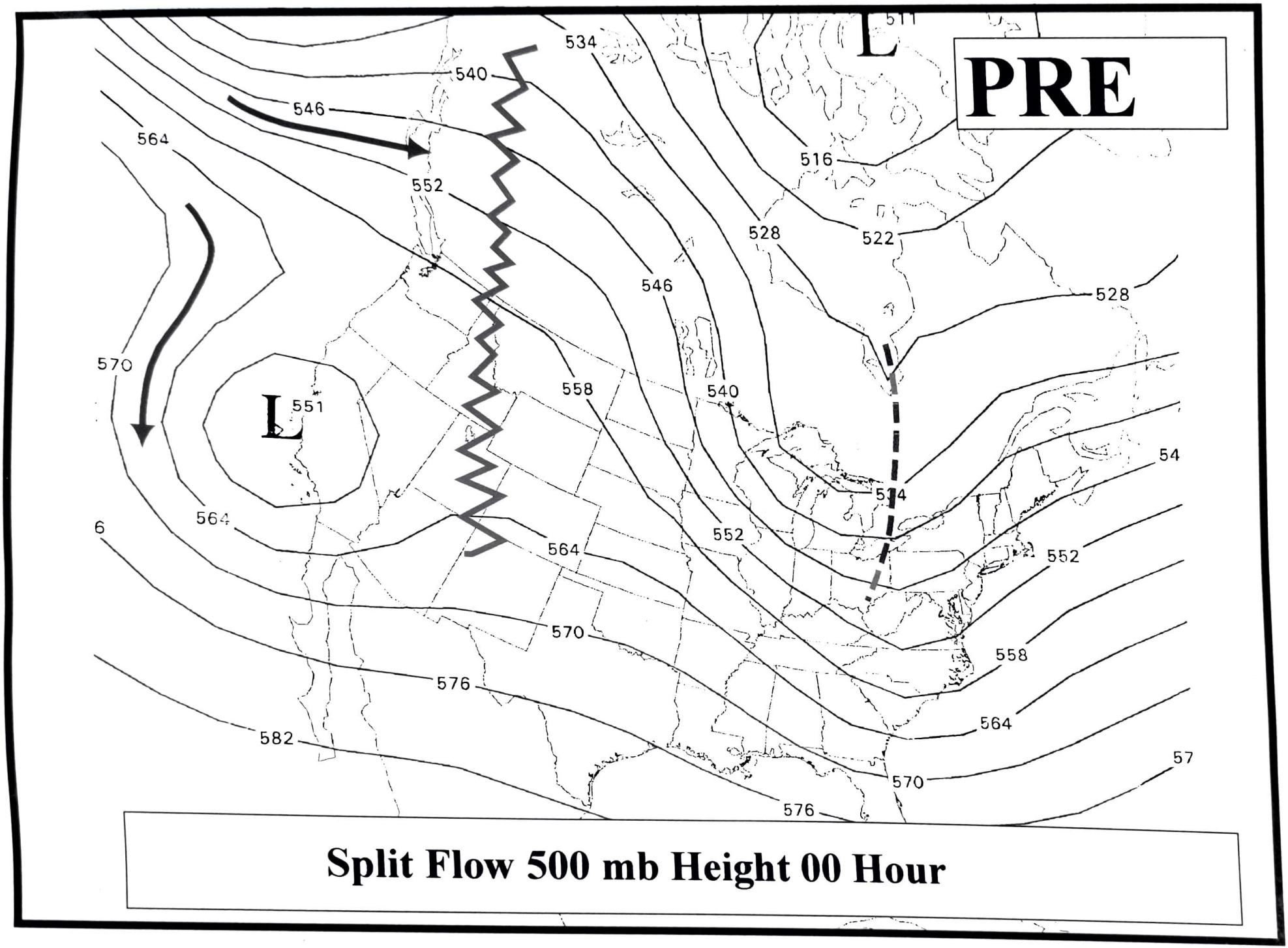
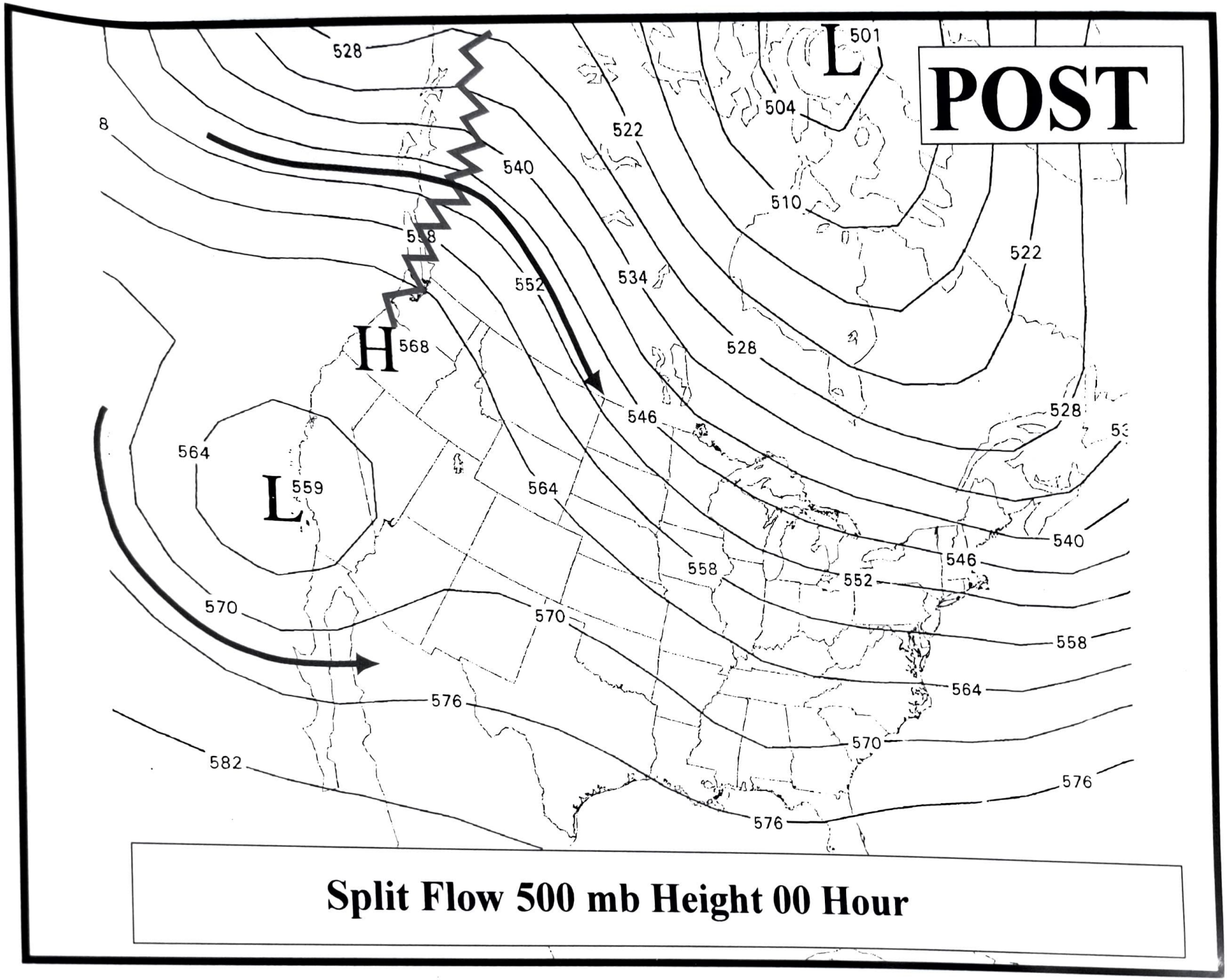
Split Flow 500 mb Temperature -24 Hour



Split Flow 500 mb Temperature -24 Hour



Split Flow 500 mb Height 00 Hour


POST
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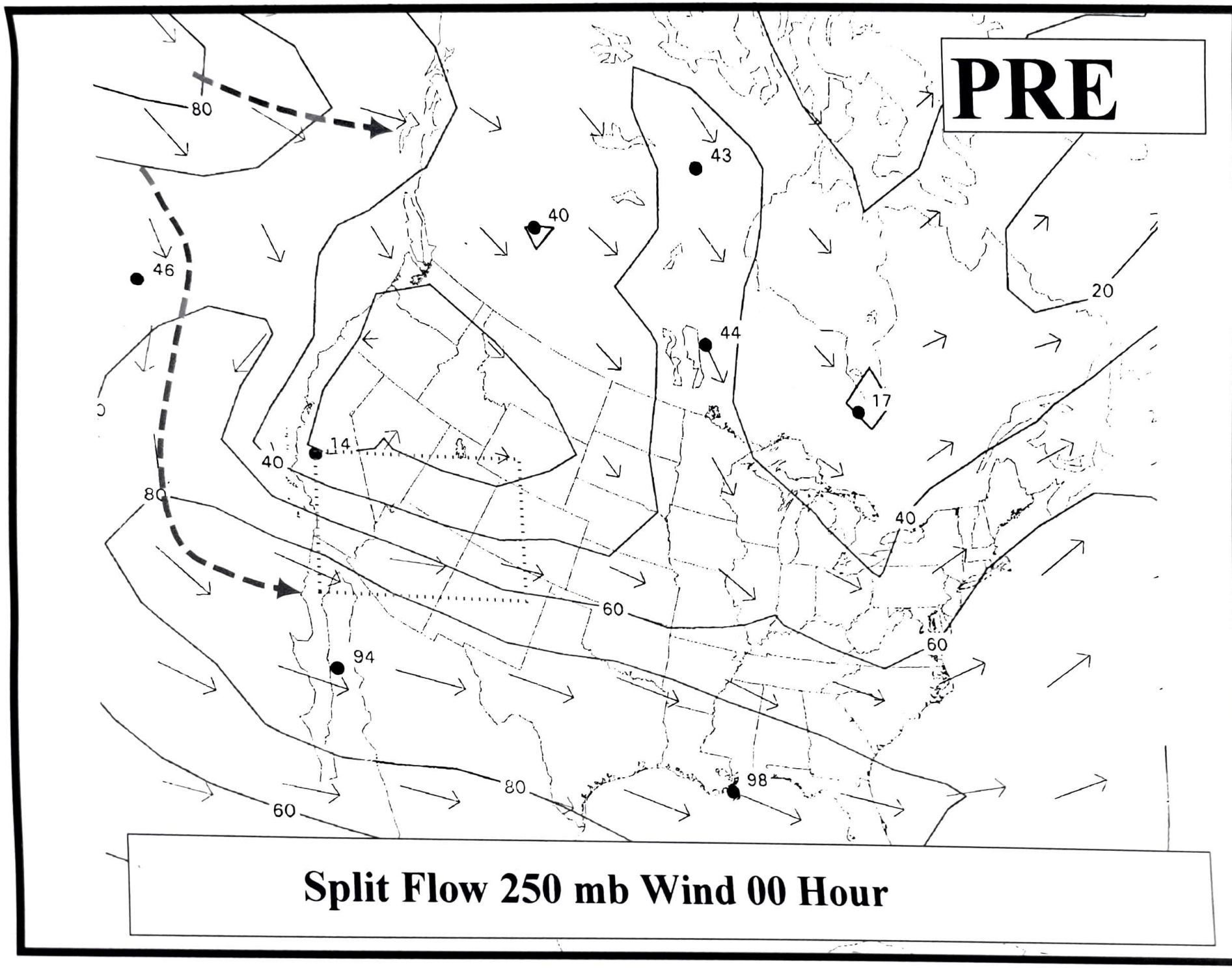
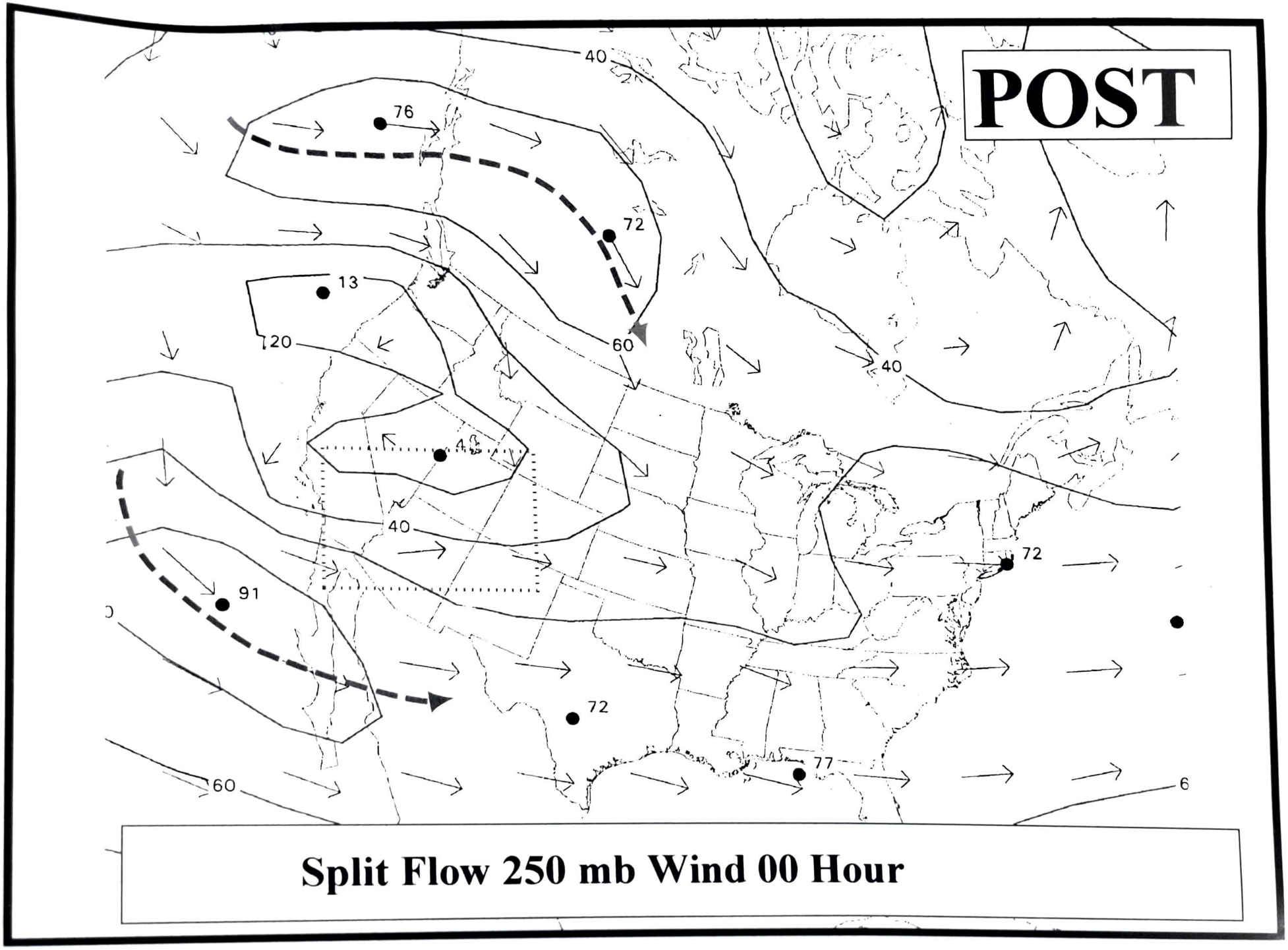
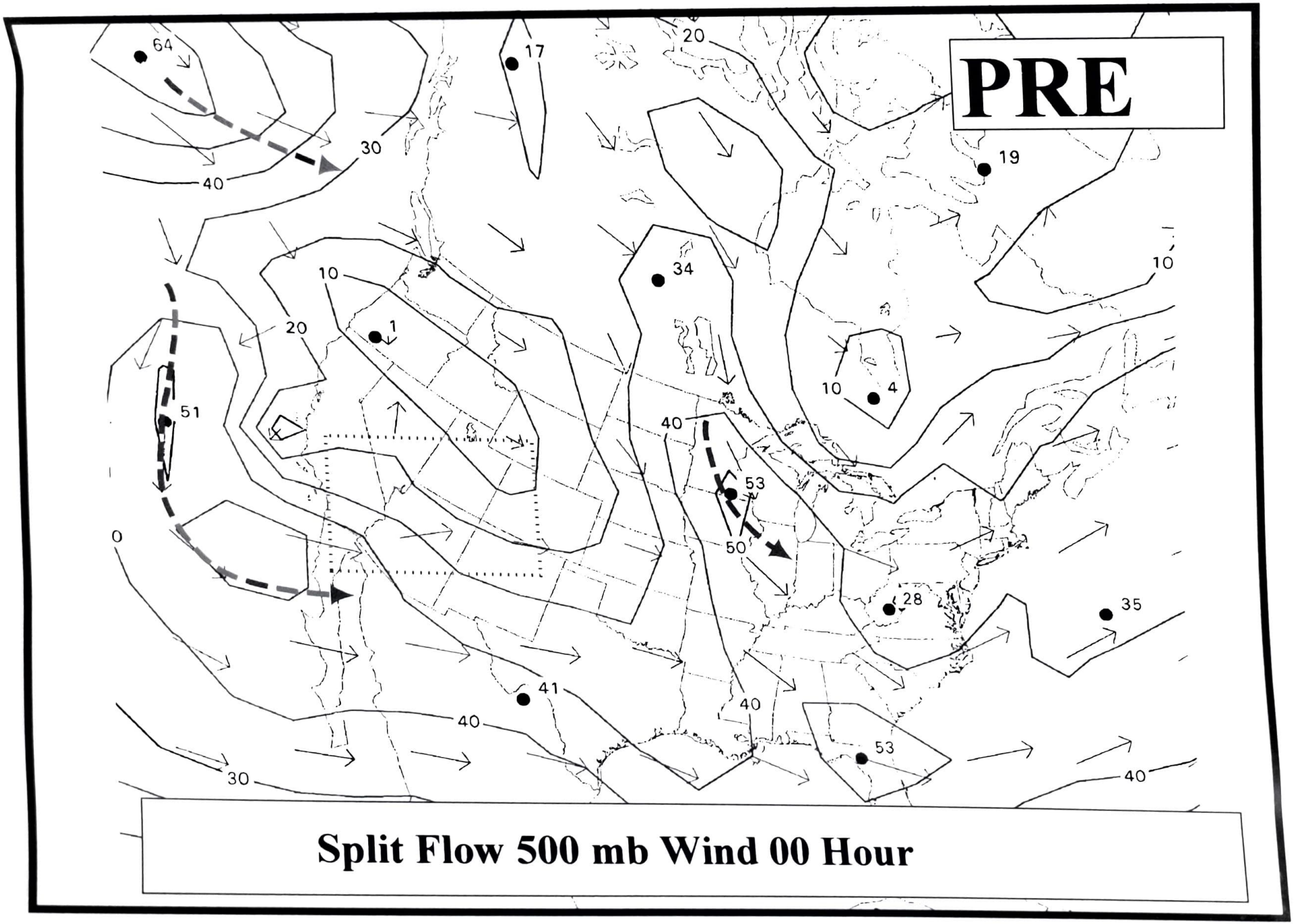
Split Flow 500 mb Height 00 Hour



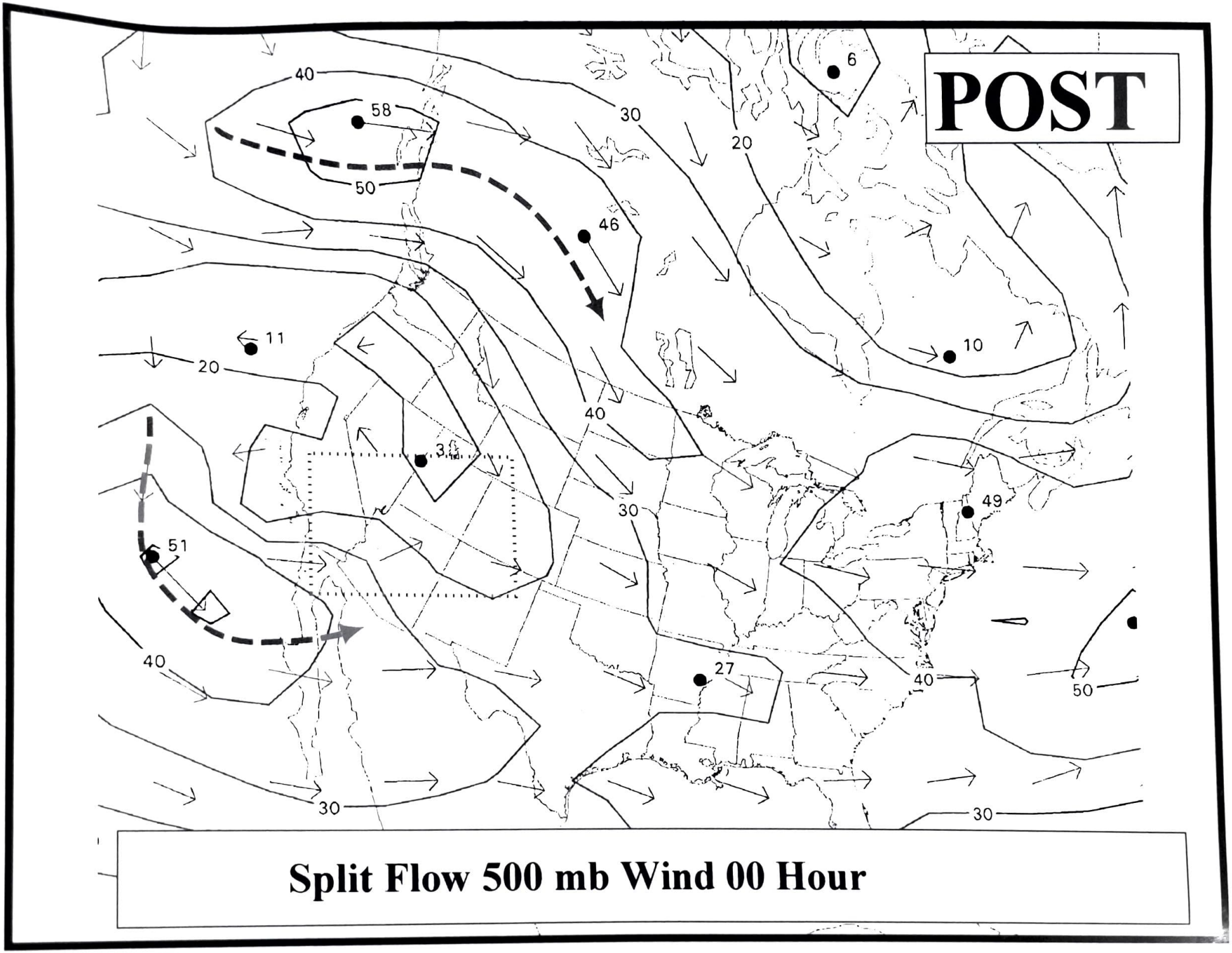
Split Flow 250 mb Wind 00 Hour



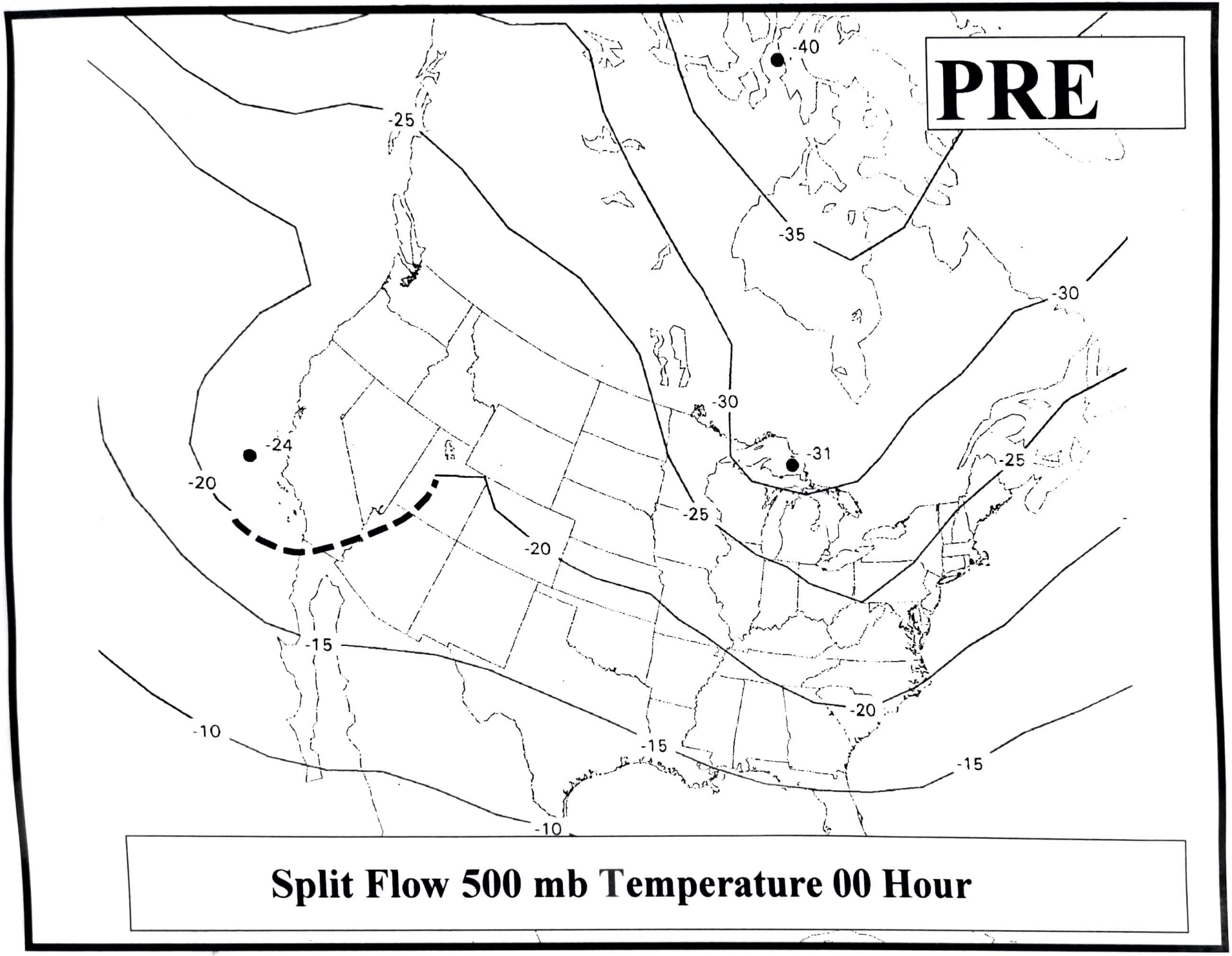
Split Flow 250 mb Wind 00 Hour



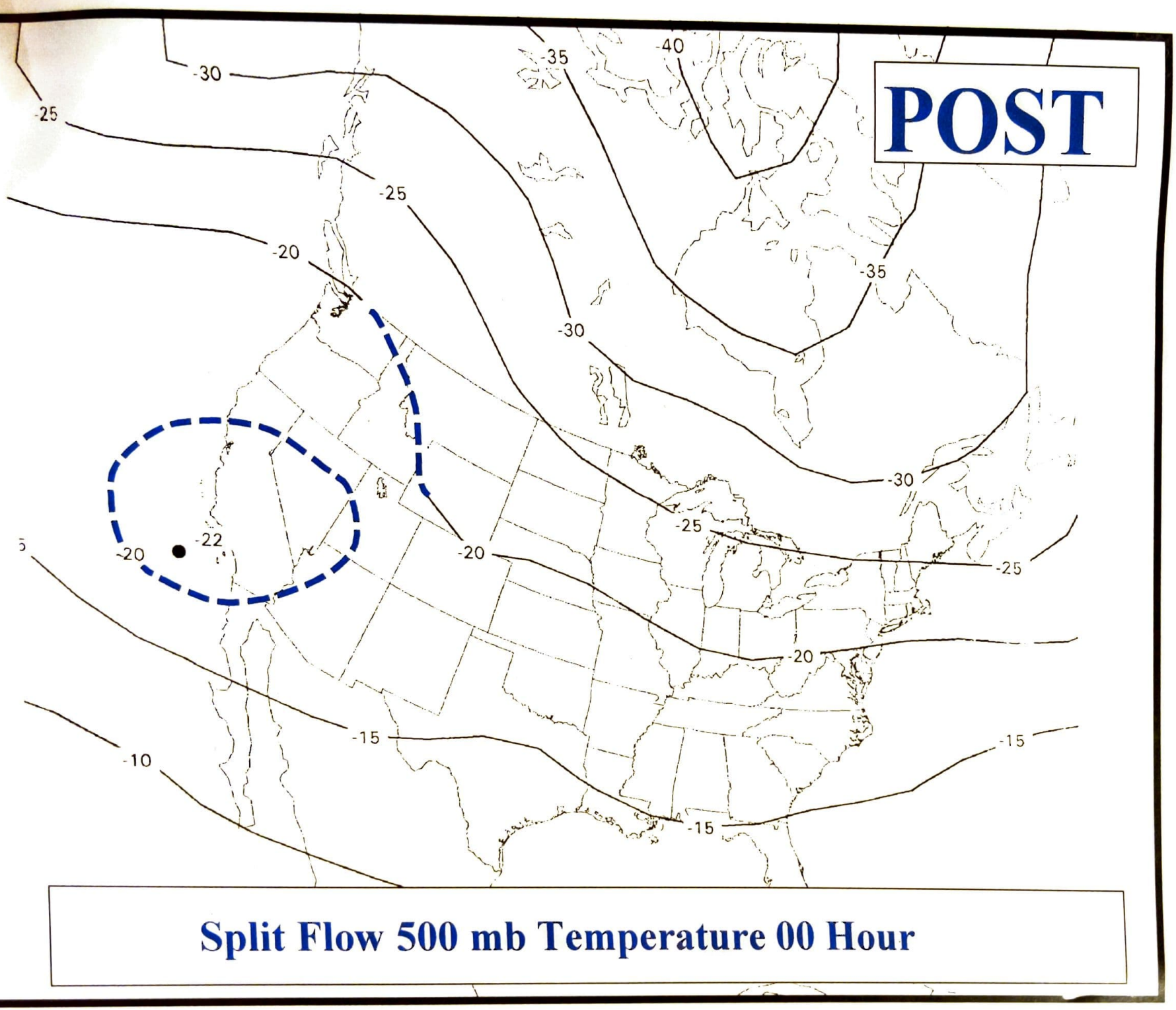
Split Flow 500 mb Wind 00 Hour



Split Flow 500 mb Wind 00 Hour



Split Flow 500 mb Temperature 00 Hour



Split Flow 500 mb Temperature 00 Hour