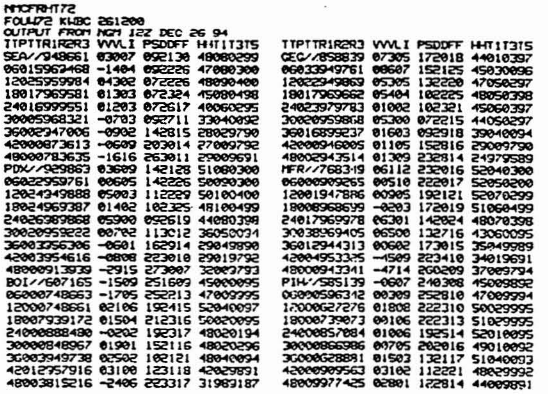
AN INDEX FOR MEASURING THE BREAKDOWN OF SURFACE-BASED INVERSIONS IN THE INTERMOUNTAIN WEST

Leslie R. Colin
National Weather Service
Boise, ID, USA

1. INTRODUCTION

Winter weather in the Intermountain West is often characterized by long periods of surface-based inversion conditions causing fog, stratus, haze, and smoke in the valleys. These inversions most often form when radiational cooling occurs during extended periods of high pressure aloft. The breakdown of an inversion is often a sudden event, resulting in rapid warming and improvements in ceiling, visibility, and air quality. Forecasting inversion breakdown is therefore important, but difficult under operational conditions. Time constraints preclude elaborate investigations of boundary layer stability, winds, and mixing potential. What is needed is a simple index for gauging inversion strength, and thresholds of that index corresponding to inversion breakdown. The purpose of this paper is to develop such an index, while trying to keep it as simple and easy to use as possible.

The U.S. National Weather Service (NWS) National Meteorological Center (NMC) routinely publishes model forecast output values in tabular form (NWS, 1985) as shown in Figure 1.



```
NMCFRHT72
FOUS72 KWBC 261200
OUTPUT FROM NGM 12Z DEC 26 94
TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5   TTPTTR1R2R3 VVVLI PSDDFF HHT1T3T5
SEA//948661 03007 092130 48080299   GEG//858839 07305 172018 44010397
06015962468 -1404 092226 47080300   06033949761 00607 152125 45030096
12025959984 04302 072226 48090400   12022949869 05305 132220 47050297
18017969581 01303 072324 45080498   18017969662 05404 102225 48050398
24016999551 01203 072617 40060295   24023979783 01002 102321 45060397
30005968321 -0703 092711 33040092   30020959868 05300 072215 44050297
36002947006 -0902 142815 28029790   36016899237 01603 092918 39040094
42000873613 -0609 203014 27009792   42000946005 01105 152816 29009790
48000783635 -1616 263011 29009691   48002943514 01309 232814 24979589
PDX//929863 03609 142128 51080300   MFR//768319 06112 232016 52040300
06022959761 00605 142226 50090300   06000909265 00510 222017 52050200
12024349888 05003 112229 50100400   12001947886 00905 192121 52070299
18024969387 01402 102325 48100499   18008968699 -0203 172019 51060499
24026389868 05900 092619 44080398   24017969978 06301 142024 48070398
30020959222 00702 113012 36050034   30038969405 06500 132716 43060095
36003356306 -0601 162914 29049890   36012944313 00602 173015 35049989
42003954616 -0808 223010 29019792   42004953325 -1509 223410 34019691
48000913939 -2915 273007 32009793   48000943341 -4714 260209 37009794
BOI//607165 -1509 251609 45000095   PIH//585139 -0607 240308 45009892
06000748663 -1705 252213 47009995   06000596312 00309 252810 47009994
12000748661 02106 192415 52040097   12000627276 01808 222310 50029995
18007939172 01504 212316 50020095   18000739073 09106 222313 51029995
24000888480 -0202 192317 48020194   24000857084 01006 192514 52010095
30000848967 01901 152116 48020296   30000866986 00705 202016 49010092
36003949738 02502 102121 48040094   36000628891 01503 132117 51040093
42012957916 03100 123118 42029891   42000909563 03102 112221 48029992
48003815216 -2406 223317 31989187   48009977425 02801 122814 44009891
```

Figure 1. NMC tabulated model forecast output.

These bulletins are issued twice daily to all NWS field forecast offices, for the 00Z and 12Z forecast cycles, for both the Eta and the NGM models. Among the categories are 1000 to 500 mb thickness (dam) in the HH column, and mean sea level pressure (mb) in the PS column. This paper will show how to use only these two quantities to derive meaningful information about the strength and breakdown of surface-based inversions.

2. METHOD

Figure 2 shows a typical example of a surface inversion. It differs from a lapse sounding by having relatively large 1000 to 500 mb thickness (HH) indicating warm air aloft, and also relatively large mean sea level pressure (PS) indicating cold air at the surface. This combination immediately suggests using the sum HH+PS as a measure of inversion strength. The larger the sum, the more likely the sounding should look like Figure 2.

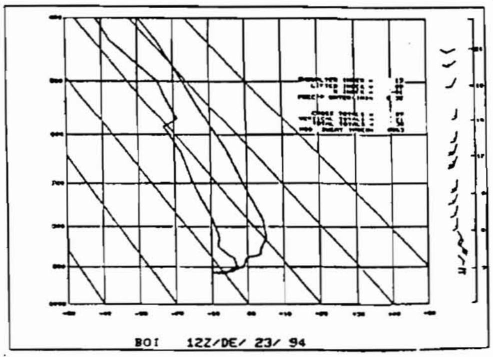


Figure 2. Pseudoadiabatic sounding illustrating a strong surface-based radiational inversion.

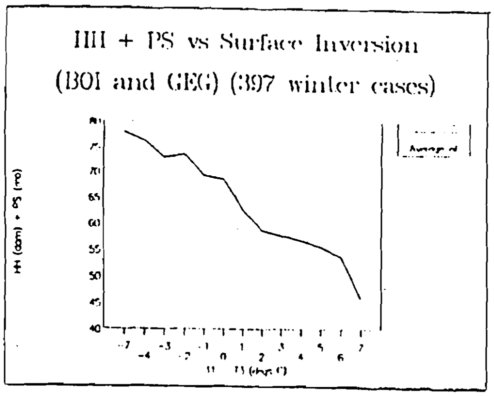


Figure 3.

Figure 3 shows that this is indeed the case during winter at the representative stations Spokane, WA (GEG), and Boise, ID (BOI). The abscissa in Figure 3 does not represent true surface-based conditions, but rather analyzed temperature difference from the lowest 35 mb layer (T1 in Figure 1) to near the 900 mb surface (T3) (NWS, 1981). The strength of an inversion, as measured by how much colder T1 is than T3 (at 00Z times only, i.e., afternoon), is shown to be correlated with large values of HH+PS. A major advantage in using HH and PS (unlike T1 and T3), is that both are also routinely available in graphical form and in historical records. When HH+PS is less than about 60, T1 is warm enough compared to T3 to promote mixing, so that the value 60 may be taken as the threshold corresponding to breakdown of the inversion.

Therefore to use this method, one merely needs to scan the HH and PS columns, noting when their sum drops below 60 (inversions generally occur with sums well above 60), and forecasting inversion breakdown at that time.

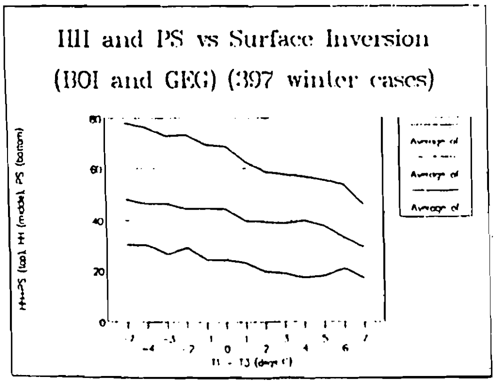


Figure 4.

Figure 4 shows values of HH and PS separately as they contribute to the sum. Note that HH and PS both increase as inversion strength (T1-T3) increases.

Figure 5 illustrates average low level moisture during surface inversions. R1 represents model analyzed relative humidity in the lowest 35 mb, while R2 represents mean humidity in the layer above it up to 500 mb. Note that R1 is usually larger than R2 during surface inversions, and that R1-R2 tends to increase as the inversions strengthen. But since the HH+PS trace is similar to the R1-R2 trace, it is not necessary to use the latter.

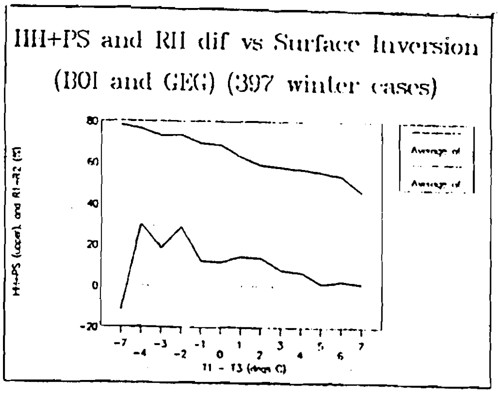


Figure 5.

Figure 6 contains information about true surface conditions, since observed maximum temperatures are included in the ordinate. Here it can be seen that observed maxima are about the same as T1 during inversions, but when T1 becomes about 4 degs C warmer than T3, observed maxima also become much warmer than T1, indicating complete mixing.

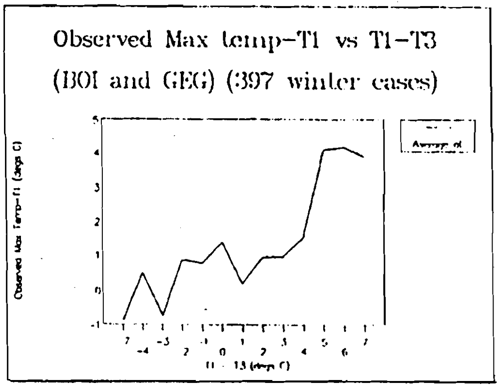


Figure 6.

Figure 7 shows how average boundary layer wind speed varies with inversion strength. In general inversion strength is insensitive to boundary layer wind speed, although there is a slight tendency for lighter winds to occur with stronger inversions.

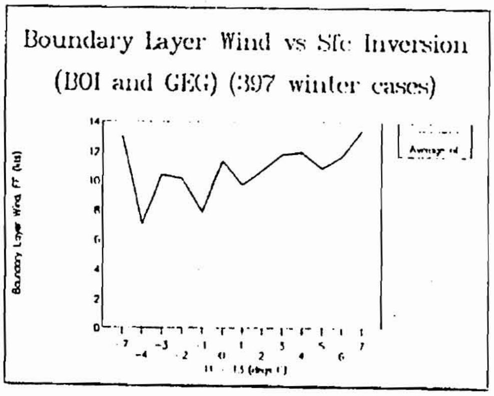


Figure 7.

2.1 Modifications in the Method

In an index as simple as HH+PS, one must be aware of several assumptions and simplifications. For one thing, HH and PS have different units. From the hypsometric equation, e.g., Holton (1979),

$$\overline{T} = \frac{g}{R} \times \frac{HH}{\ln\left(\frac{PS}{500}\right)} \qquad (1)$$

where T is mean virtual temperature from sea level to 500 mb, g is gravity, R the gas constant, HH thickness from sea level to 500 mb (i.e., 500 mb height), and PS sea level pressure, it is seen that a change in HH of 1 dam corresponds to a change of about 1.2416 mb in PS when typical values of 560 dam are used for HH, and 1000 mb for PS. After normalizing, the index becomes HH+1.2416PS. Figure 8 shows the modified relationship to T1-T3 inversion strength. Note that little additional benefit is gained using the modified index.

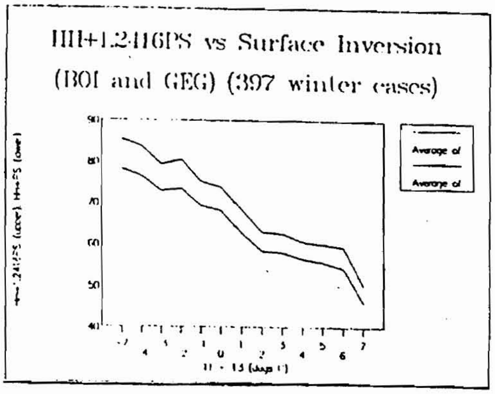


Figure 8.

It is assumed that changes in PS affect temperatures only near the surface, while changes in HH affect temperatures uniformly throughout the entire 1000 mb to 500 mb layer. This assumption is justified indirectly as follows:

Since HH is large in summer, large values of HH+PS can also occur in summer. Figure 9 shows that HH+PS has maxima in both summer (when T1-T3 is large) and in winter. During summer, afternoon surface-based inversions never occur, i.e., there is always a lapse condition. Therefore, increases in HH must be felt all the way to the surface, resulting in a positive correlation between HH and surface temperature.

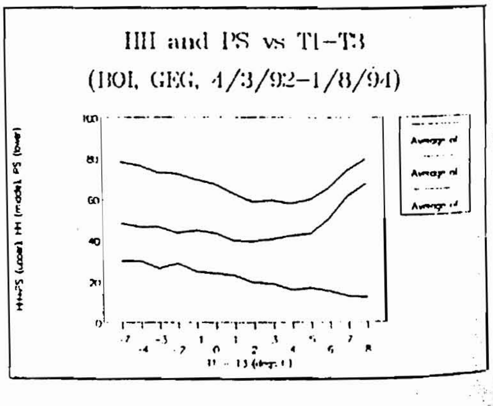


Figure 9.

But note from Figure 9 that it is the difference HH-PS which correlates very strongly with T1-T3 lapse rate during summer. For this to happen, PS must be playing only a minor role.

In winter, on the other hand, changes in HH often do not affect conditions near the surface. In other words, surface temperature seems to be controlled by PS in the winter and by HH in the summer. This explains why it is possible for HH+PS to have maxima in both summer and winter.

We now have the results that the sum HH+PS correlates well with T1-T3 during winter, while the difference HH-PS correlates well with T1-T3 during summer.

The two results can be combined by multiplying PS by a parameter which ranges from -1 in summer to +1 in winter, and then adding to HH.

3. SUMMARY

The simple combination of HH+PS, taken from routine NMC-published numerical forecast output, provides a means of evaluating the strength of surface inversions in the intermountain region of the western U.S., in which inversion strength itself is measured by the magnitude of T1-T3. Surface inversions usually occur when HH+PS is larger than 60, but tend to break when HH+PS falls below 60. Large values of HH+PS during summer are due to large values of HH alone, and are not associated with surface inversions. Normalizing units of HH and PS provides little if any additional benefit over using HH+PS directly.

4. REFERENCES

Holton, J.R., 1979. An Introduction to Dynamic Meteorology. Academic Press, New York. 391 p.

National Weather Service, 1985. FOUS Messages from the RAFS. NWS Tech. Procedures Bull. No. 351, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 7 p.

HH + PS vs Surface Inversion

(BOI and GEG) (397 winter cases)

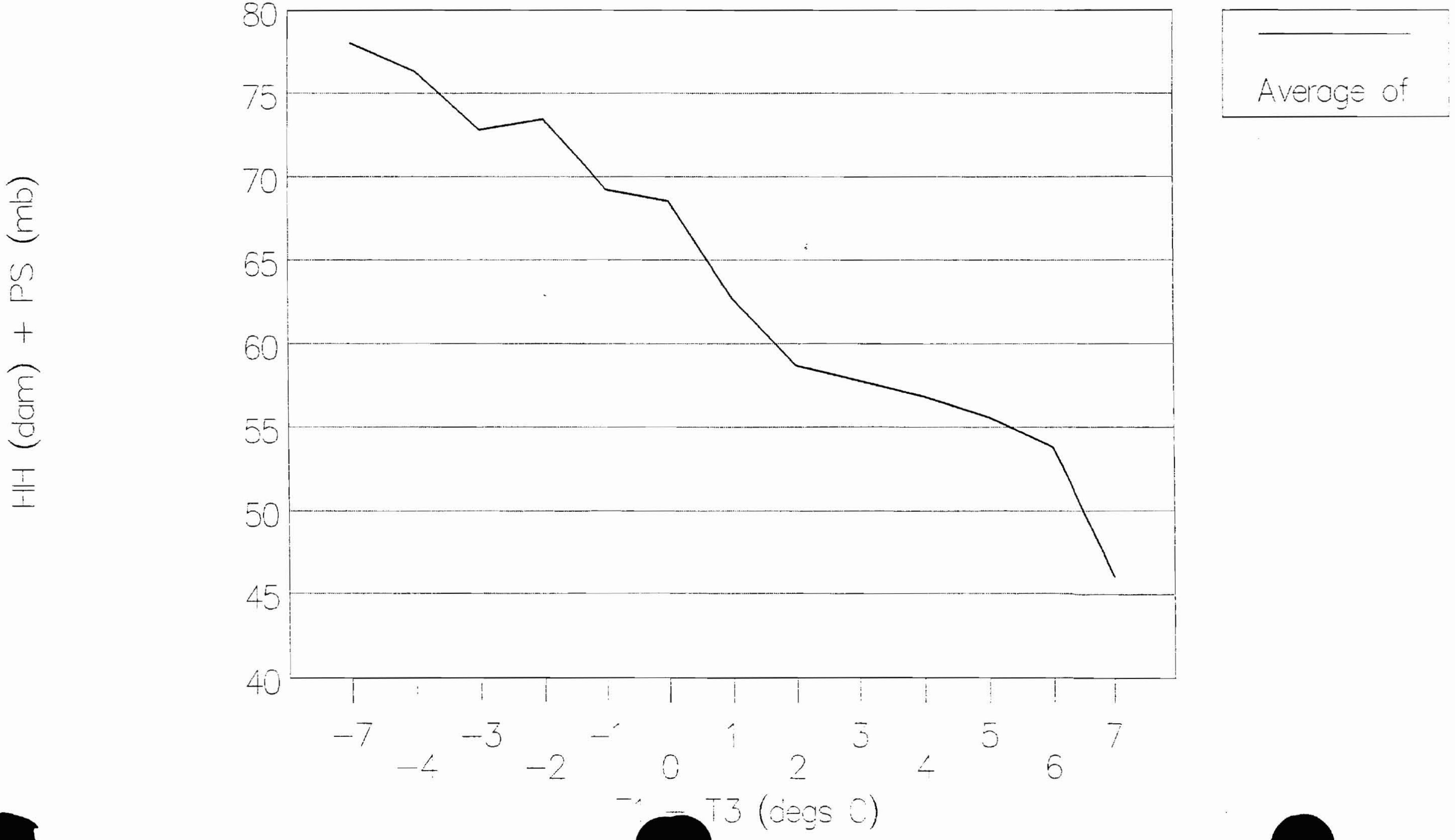


FIG. 1

HH and PS vs T1–T3

(BOI, GEG, 4/3/92–1/8/94)

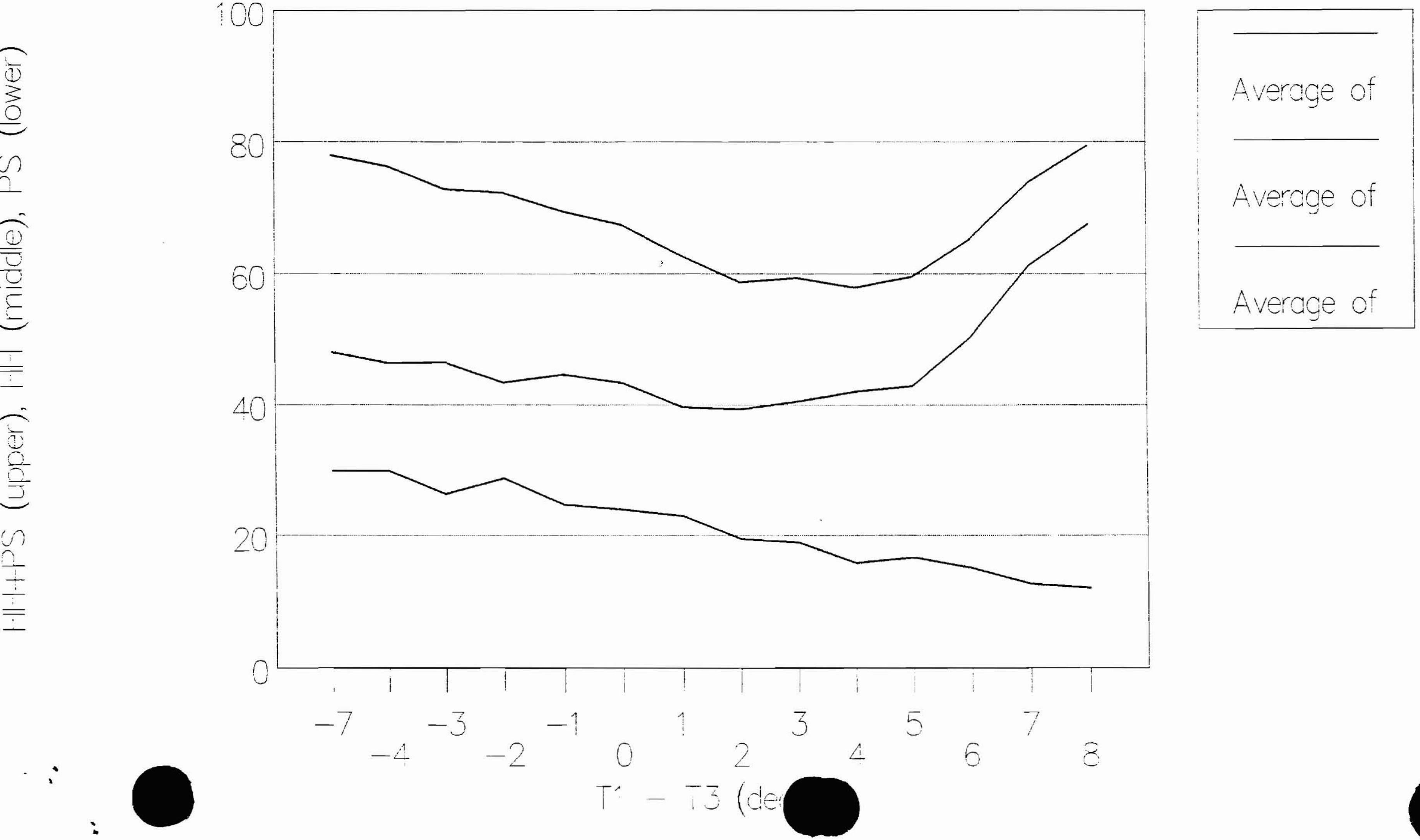


FIG 3

SURFACE BASED INVERSION INDEX (HH + PS)

1. On the FOUS tables FRH72 or FRTH72, find the sum HH + PS.

2. Refer to Figure 1. High numbers of HH + PS (greater than about 68) correspond to surface-based inversions, indicating a combination of cold air at the surface (high PS) and warm air above (high HH).

   The left half of Figure 1 indicate surface-based inversions (when T1 is colder than T3), T1 being temperature 35 mb above the model surface, and T3 the temperature near 900 mb.

3. Figure 2 shows how HH and PS contribute to the sum HH + PS. During winter inversions, PS dominates. During summer, HH dominates.