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A Paradox Principle in the Prediction of Precipitation Type

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U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

NOAA Technical Memorandum NWSTM WR-72

A PARADOX PRINCIPLE IN THE PREDICTION OF PRECIPITATION TYPE

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WESTERN REGION
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A PARADOX PRINCIPLE IN THE PREDICTION OF PRECIPITATION TYPE

ABSTRACT

Utility of 1000 - 500-mb thickness in forecasting precipitation type can be enhanced significantly by also considering the mean lapse rate in that layer. This can be done readily by relating thickness to 500-mb temperature. The 500-mb temperature is a relatively easy parameter to forecast in comparison to the uncertainty of temperature forecasts for lower levels. The paradox is developed that inclusion of 500-mb temperature produces a diametrically opposite effect to that which might be expected.

I. INTRODUCTION

Precipitation forecasting is more than a question of occurrence or nonoccurrence as has been the object of most studies. Type of precipitation has received much less attention. This may be attributable to precipitation forecast verification systems which are concerned only with amount and totally ignore type. Precipitation type is of great practical importance. One inch of rainfall may be little more than a wet inconvenience; the same amount of precipitation falling as snow may paralyze a community with a blanket of a foot or more. The need for further investigation on this problem has been pointed out by the National Weather Service's Western Region Scientific Services Division. In discussing uses for thickness forecasts by teletype head "FOUS" the comment is made, "Examination of relationships between thickness and rain versus snow occurrence is needed" [1].

The type of precipitation occurring in a given air mass is closely related to the thickness, or mean temperature, of a shallow layer near the surface such as the 1000 - 850-mb layer. It is less closely related to the thickness of the deeper 1000 - 500-mb layer. The thickness of a shallow layer is, however, much more difficult to forecast than that of a deep layer. Also there are very few objective forecasts available for such shallow layers, and what little is available or can be derived does not have the necessary precision for successful precipitation type forecasting.

In contrast, there is an abundance of facsimile prognostic material for the 500-mb level available, as well as computer produced 1000 - 500-mb thickness values available on teletype on "FOUS" transmissions. This deeper layer is by far the most practical one for use in forecasting precipitation type. This thickness can be a valuable forecasting tool in the important rain versus snow decision, especially if the mean lapse rate of the layer is also considered.

Thickness, or mean temperature, of the 1000 - 500-mb layer has been the subject of numerous investigations, ably summarized by Penn [2]. One of the more comprehensive of these studies was made by Wagner [3]. Wagner's charts indicate an equal probability of rain or snow, for a 1000 - 500-mb thickness of approximately 17,400 feet (5304 meters) for Walla Walla, Washington. Wagner's figure is in close agreement with this investigation which determined a critical value of 5323 meters for thickness considered alone.

II. THE BASIS OF THE "PARADOX PRINCIPLE"

The concept of warmer air at 500-mb favoring the production of snow and colder air favoring rain may appear preposterous without further examination. Nevertheless, the logic of the concept can be readily demonstrated as illustrated in Figure 1.

Shown are two sample vertical temperature soundings between 1000 and 500 mb. A constant lapse rate is assumed in each case for simplicity. The solid line, representing the snow case, S,S', has a small lapse rate with -20C at 500 mb and 0C at 1000 mb. The dashed line, representing the rain case, R,R', has a steeper lapse rate with -25C at 500 mb and +5C at 1000 mb.

The mean temperature through the layer is the same for each sounding, that is, the 1000 - 500-mb thicknesses are the same in each case. Note that the snow case has a higher temperature at 500 mb than does the rain case.

The principle is therefore proposed that, for a given thickness value, the warmer the air at 500 mb the greater the probability of precipitation occurring in the form of snow rather than rain, and vice versa. This is the "paradox principle".

With a major part of the forecaster's attention being focused on the 500-mb chart and its temperature pattern, this may be somewhat surprising.

III. DATA INVESTIGATED

Data required for investigations of this hypothesis were the 1000 - 500-mb thickness, the 500-mb temperature, and associated precipitation type. In this study 500-mb heights and temperatures for 1200 GCT were extracted from printed "Daily Weather Maps" published by the National Weather Service. One thousand-millibar heights were derived from Walla Walla station pressures. Since Walla Walla's barometer elevation of 976 feet msl averages quite close to the 1000-mb level, a straight-line conversion was used based on the U. S. Standard Atmosphere as given in Smithsonian Meteorological Tables [4].

Developmental data were taken from the months of December, January, and February for the winters 1968-69 and 1969-70. Cases included were all those which had a measurable amount of precipitation for the 12-hour period centered on 1200 GCT, that is, from 0600 GCT to 1800 GCT. Cases of both rain and snow, or of sleet, were not included. Freezing rain was classified as "rain". A total of 61 cases was obtained consisting of 25 cases of snow and 36 cases of rain.

IV. EVOLUTION OF A TYPE INDEX

A pictorial representation of the joint relationship among the 1000 - 500-mb thickness, 500-mb temperature, and the type of precipitation (rain or snow) is shown in Figure 2. Symbols are conventional with dots for rain cases and asterisks for snow. A line of "best separation" between rain and snow might easily be drawn on this chart by "eye", but it was felt that a more stable solution would result by using statistical technique to determine the line of "best separation"; in this case, a linear discriminant analysis was made. Such an analysis [5], resulted in the following discriminant function:

$$L = 30.7514 + .0567T - .0055K$$

where T = 500-mb temperature in degrees Celsius

k = 1000 - 500-mb thickness in meters.

For convenience of calculation, this function was converted to the following by dividing through by .0055, changing signs and setting the result equal to Y:

$$Y = -\frac{L}{.0055} = K - 10.3T - 5591.$$

Zero values of the discriminant function or precipitation type index, Y, are represented by the solid slanting line in Figure 2. Y will have positive values at points above the line in the "rain" area, and negative values below the line in the "snow" area. Note that the slope of the Y = 0 line clearly substantiates the "paradox principle".

Similar functions were computed for each of the variables alone which resulted in the following discriminant values:

$$T = -26.02\ ^{\circ}C$$

$$K = 5323\ m.$$

These values are represented in Figure 2 by the vertical and horizontal dashed lines.

The general equation for the type index, Y, would be:

$$Y = K - aT - C.$$

This equation appears useful at other locations, provided the local values of the constants a and C are determined by empirical investigation.

V. COMPARISON OF PREDICTORS

The relative accuracy of the three predictors, Y (type index as described above), K (thickness alone), and T (temperature alone), were compared using the critical value of each which produced the optimum relationship to precipitation type. Considering each indication as a "forecast", results are shown in Table 1.

The 1000 - 500-mb thickness is a fair discriminator between rain and snow, and is certainly better than the 500-mb temperature. Due to the "paradox principle", however, combining 500-mb temperature with thickness results in an index which shows significant improvement over thickness alone.

VI. TESTING ON INDEPENDENT DATA

Critical values of Y, K, and T as determined from the two developmental winters were tested on independent data from the winter 1970-71. Data were extracted in the same manner as for the developmental winters. Results are shown in Table 2.

This 1970-71 winter was abnormally dry and mild, affording only 17 cases for testing. Although the predictor Y showed a gratifying high accuracy (only one erroneous forecast), this was undoubtedly higher than could normally be expected. Still, it showed results superior to the other two predictors. The overall record for the predictor Y for all three winters, two of developmental data and one of independent testing, shows an accuracy of 88.4%, which may be considered a more representative evaluation.

VII. APPLICATION IN FORECASTING

The Y value may be computed for each 12-hour interval for which radiosonde data are available and plotted on a running graph. For locations not near a radiosonde station, the 500-mb height and temperature may be extracted from facsimile charts. The 1000-mb height may be computed from station pressure at locations suitably near that level, or it may be taken from sea-level pressure using the formula:

$$H = 8(P - 1000)$$

where H = 1000-mb height in meters and

P = sea-level pressure in millibars.

(The precise factor according to Smithsonian Tables is 8.0008 geopotential meters per millibar change in pressure, at 0 C and 1000 mb) [4].

With thickness forecasts available twice daily by teletype (headed "FOUS"), as well as 18,000-foot temperatures on the FD forecasts, the Y value may be extrapolated. Using 24-hour thickness forecasts on FOUS and the third section of the FD forecasts, the Y values may be projected for 24 hours. The nighttime transmissions will produce Y projections for 0000 GCT the following afternoon, and the midday transmissions the Y value for 1200 GCT the following morning.

Stations not located at grid points for which FOUS and FD forecasts are made may effectively employ interpolation methods because of the usual smoothness of values at the 500-mb level. Temperature at the 500-mb level may not, of course, be identical with that at 18,000 feet (5486 meters) due to variations in the 500-mb surface. Compensation for this can be made by noting the prognostic 500-mb height and applying an appropriate temperature correction. This correction involves raising the 18,000-foot temperature when the 500-mb height is less than 18,000 feet (5486 meters) or lowering it when the 500-mb height is above that level. The standard tropospheric lapse rate according to Smithsonian Meteorological Tables [4] is 0.0065 degrees Celsius per meter, or one degree Celsius for each 154 meters (to whole meters). Correction values are given in Table 3.

Figure 3 illustrates a sample Y chart with values determined each 12 hours. Twenty-four hour projections based on the FOUS and FD forecasts are plotted as small Xs.

Projections of Y for more extended periods based on facsimile prognostic charts have thus far met with only limited success. Although positions of major features are usually rather good on these charts, absolute heights are frequently inaccurate. This may be due to sparseness of data over the ocean as most inaccuracies are most marked over the western United States.

VIII. SUMMARY

The Y value based on the "Paradox Principle" appears to be a substantial improvement over use of thickness alone in the important distinction between rain and snow. It is readily computed from parameters for which computer forecasts are now available. It appears suitable for use at locations other than Walla Walla, Washington, provided local values of the constants are determined by empirical investigation.

IX. ACKNOWLEDGMENT

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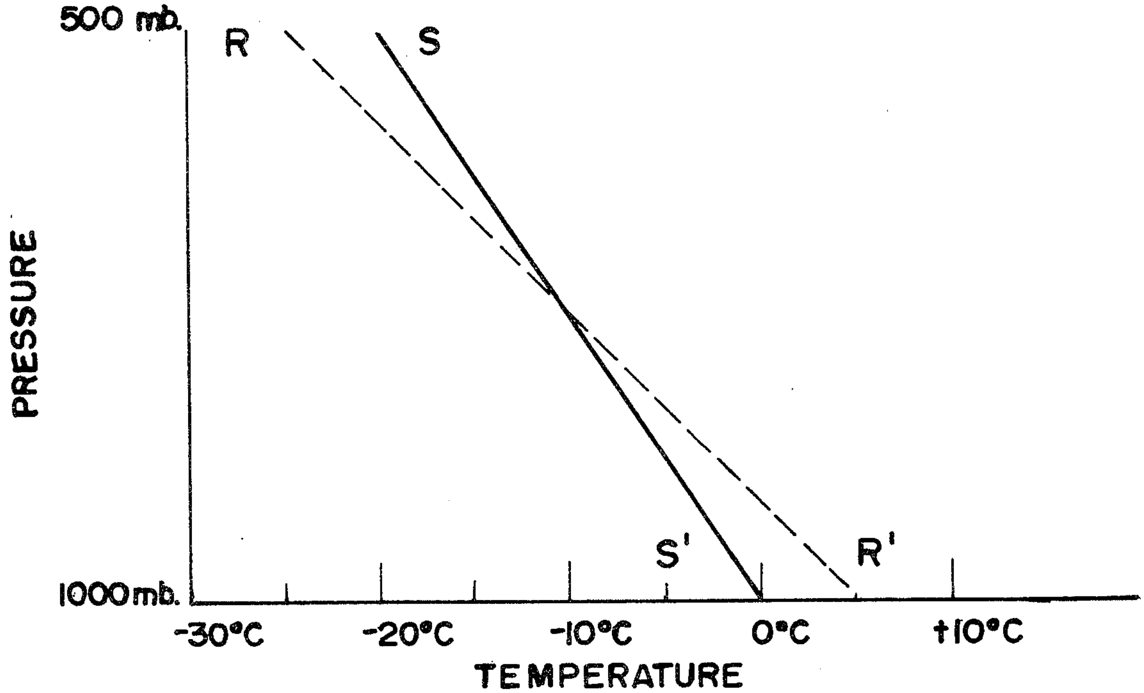

FIGURE 1. ILLUSTRATION OF THE "PARADOX PRINCIPLE".

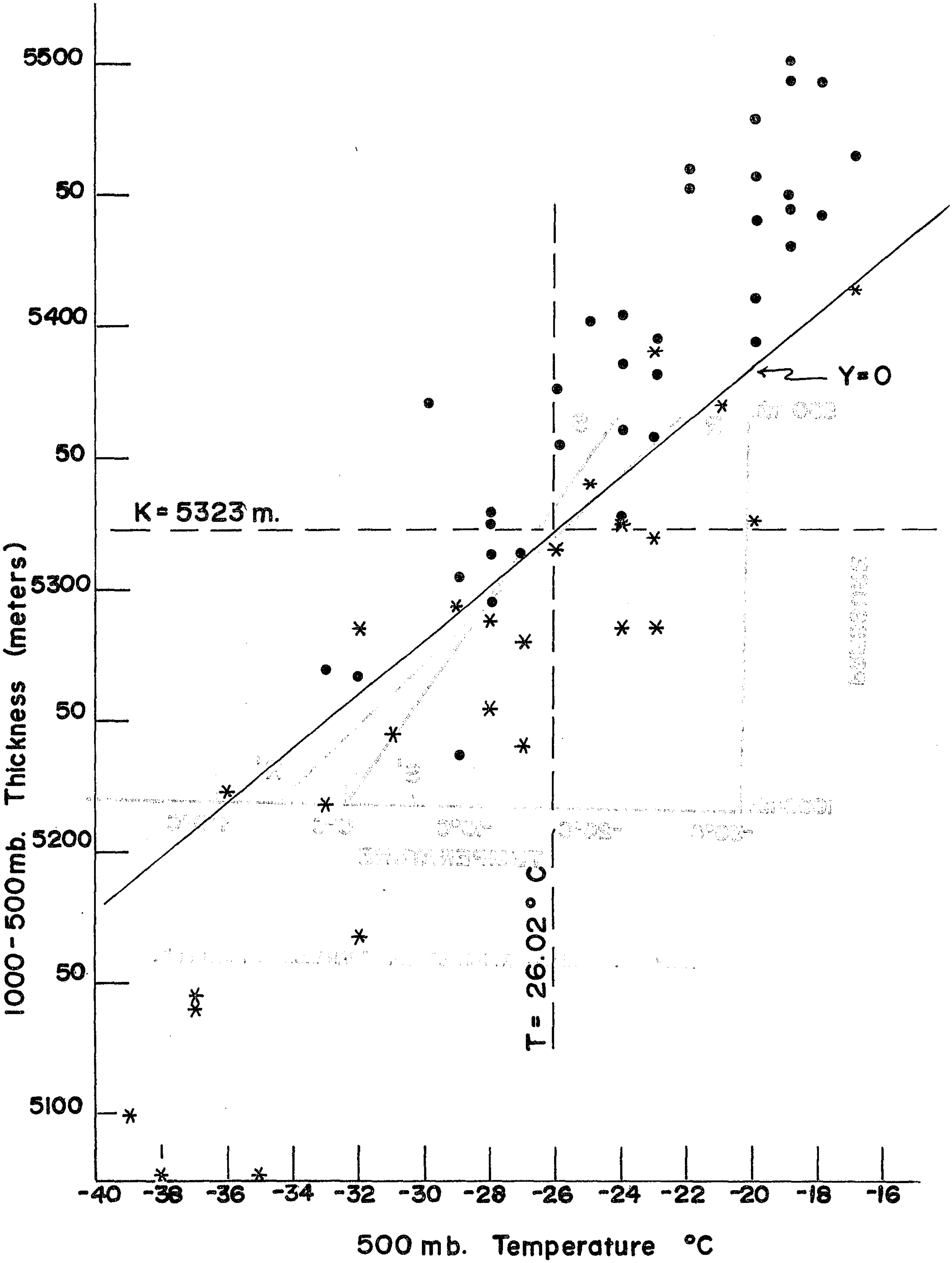

FIGURE 2. RELATIONSHIP OF RAIN (•) AND SNOW (*) OCCURRENCES TO 1000 - 500-MB THICKNESS (K) AND 500-MB TEMPERATURE (T).

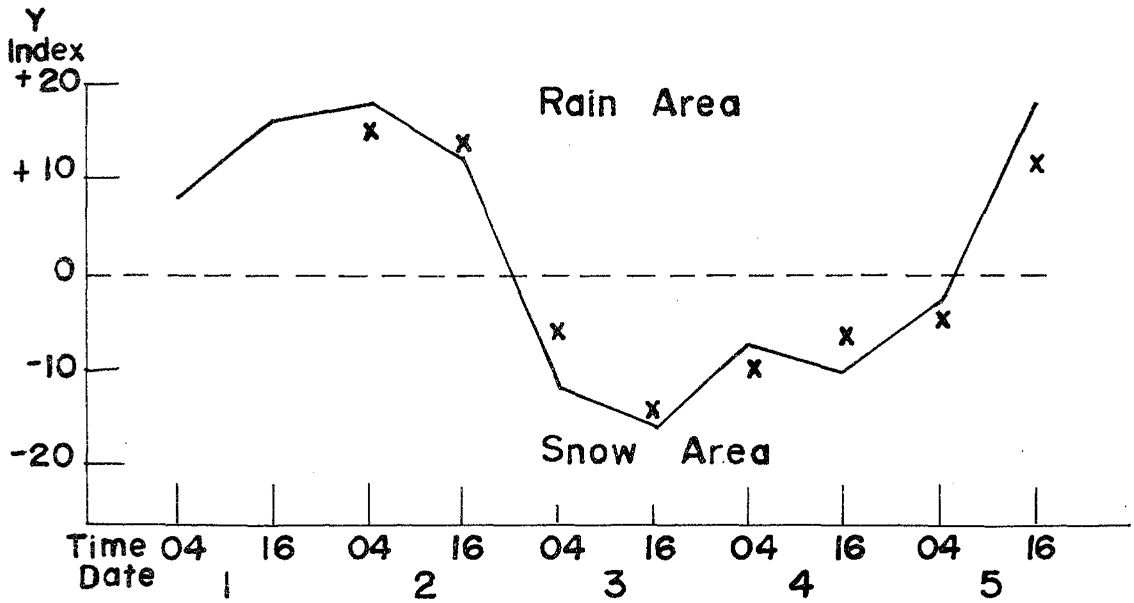

FIGURE 3. A SAMPLE GRAPH OF THE Y-INDEX. THE SOLID LINE IS A RUNNING GRAPH OF ACTUAL VALUES AT 12-HOUR INTERVALS; "Xs" ARE 24-HOUR PROJECTIONS.

TABLE 1

SUMMARY OF DEVELOPMENTAL DATA

CATEGORICAL "BEST FIT" FORECASTS	Y	K	T
Rain forecast, rain occurred	33	28	26
Rain forecast, snow occurred	5	6	10
Snow forecast, rain occurred	3	8	10
Snow forecast, snow occurred	20	19	15
Total cases correct	53	47	41
Total cases incorrect	8	14	20
Percent correct	86.9	77.0	67.2

TABLE 2

TESTING ON INDEPENDENT DATA

CATEGORICAL "BEST FIT" FORECASTS	Y	K	T
Rain forecast, rain occurred	11	9	8
Rain forecast, snow occurred	0	0	2
Snow forecast, rain occurred	1	3	4
Snow forecast, snow occurred	5	5	3
Total cases correct	16	14	11
Total cases incorrect	1	3	6
Percent correct	94.1	82.3	64.7

TABLE 3

CORRECTION TO BE APPLIED TO THE TEMPERATURE AT
18,000 FEET TO APPROXIMATE THE CORRESPONDING TEMPERATURE AT 500 MB

500-MB HEIGHT IN DECAMETERS	CORRECTION DEGREES C.
495 to 510	+3
511 to 525	+2
526 to 540	+1
541 to 556	0
557 to 571	-1
572 to 587	-2
588 to 602	-3

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