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Standardizing Growing Degree Day Totals for Differences in Temperature Observing Schedules

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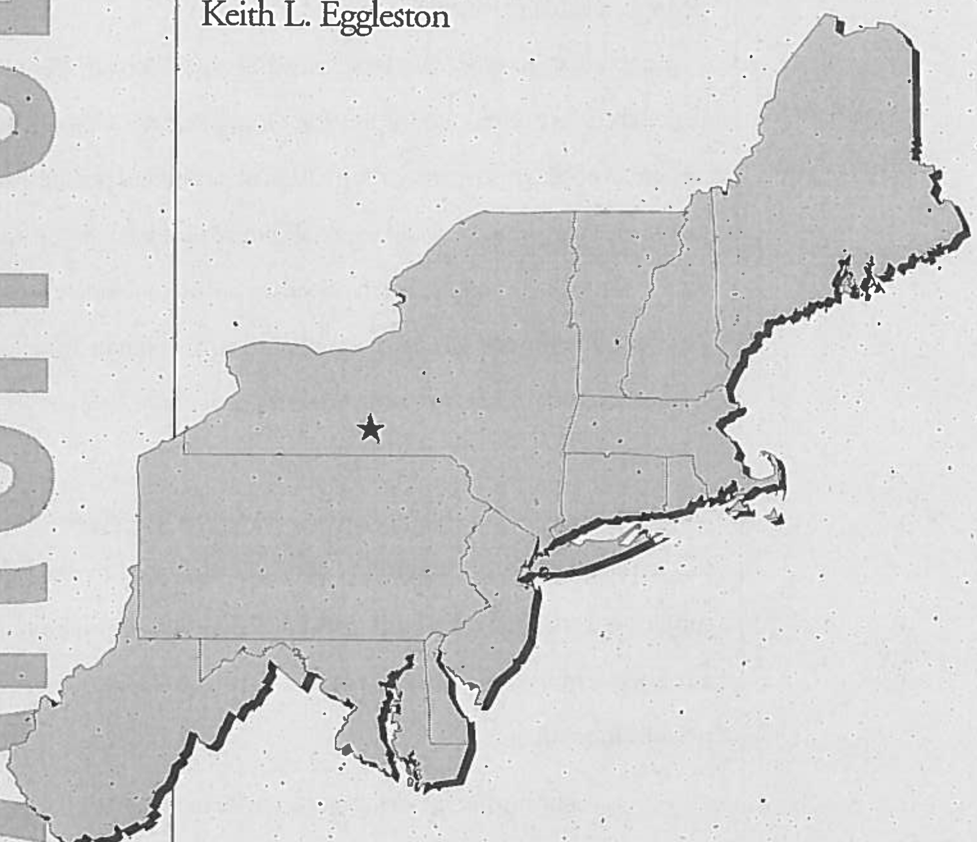

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INTRODUCTION

Differences in observing and reporting practices for daily maximum and minimum temperatures between U.S. and Canadian stations, as well as differences in observing times among observation sites in the U.S., introduce small differences in reported daily temperature extremes. When used in growing degree day (GDD) calculations, these small differences accumulate over time, resulting in significant inconsistencies in weekly or longer period GDD totals among stations. When used in near-real time, GDD accumulations affected by these differences may lead to delayed or premature scheduling of climate sensitive agricultural operations.

Several studies have documented problems when comparing GDD accumulations at different sites and have developed adjustment procedures for the systematic bias resulting from observation time differences. Baker (1975) focused his adjustment scheme on seasonal, May–September, base 50 GDD at St. Paul, MN. Schaal and Dale (1977) calculated monthly standardization factors for 86-50 method GDD in Indiana. However, their work was limited to adjusting 0700 and 1900 observations to midnight values. [For convenience in graphical and tabular presentations, twenty-four hour time is used throughout this publication.] Blackburn (1983) also developed a method by which monthly average temperatures could be adjusted for observation time bias. Implementation of his adjustment scheme, however requires access to hourly temperature data which are available at only a few sites.

Due to the limitations associated with the previous standardization methods, DeGaetano and Knapp (1993) developed a more flexible method to standardize weekly GDD totals, based on any observation time or the Canadian observation method to a common observation hour. This adjustment procedure can be successfully applied to data from any station in the northeastern United States or southeastern Canada and requires only daily temperature data for the week of interest. In addition, GDD totals calculated using each of the three most common methods, base 50 (GDD50), 86-50 (GDD86-50) and Canadian Corn Heat Units (CHU), can be standardized using the adjustment procedure.

CAUSES OF OBSERVATION TIME BIAS

Daily temperature extremes are typically recorded at one of three times: morning (0700–0800), early evening (1600–1900) or midnight (2400) and are intended to represent the preceding 24 hour period. While temperature averages from midnight observations tend to be slightly cooler than those taken at the most common observation hours, 0700 and 0800, average temperatures calculated from afternoon observations tend to be warmer. This warm bias results because afternoon observation hours coincide with the normal time of maximum temperature occurrence. If a warm afternoon is followed by a day with cooler temperatures, the maximum temperature observation taken during the warm afternoon will likely represent the maximum temperature of both the current and subsequent 24-hour periods since, once reset, the thermometer will remain at or near the maximum temperature. In effect this maximum temperature is recorded twice. Thus, sites that make observations about the time of the daily maximum temperature tend to accumulate GDD more rapidly than do stations taking morning or midnight observations.

Conversely, GDD accumulate less rapidly when daily temperature observations are taken near the time of the daily minimum temperature occurrence (generally 0500–0600), since the minimum temperature on a particularly cold morning is often recorded as the minimum for two successive days. More generally, maximum and minimum temperatures can occur at any time of the day. This introduces a certain degree of observation time bias (OTB) to any observation hour. However, when compared with GDD calculated using the average of 24 hourly temperature values, this bias tends to be small for observations taken at 0800. Figure 1 shows the typical pattern of observation time bias versus observation hour.

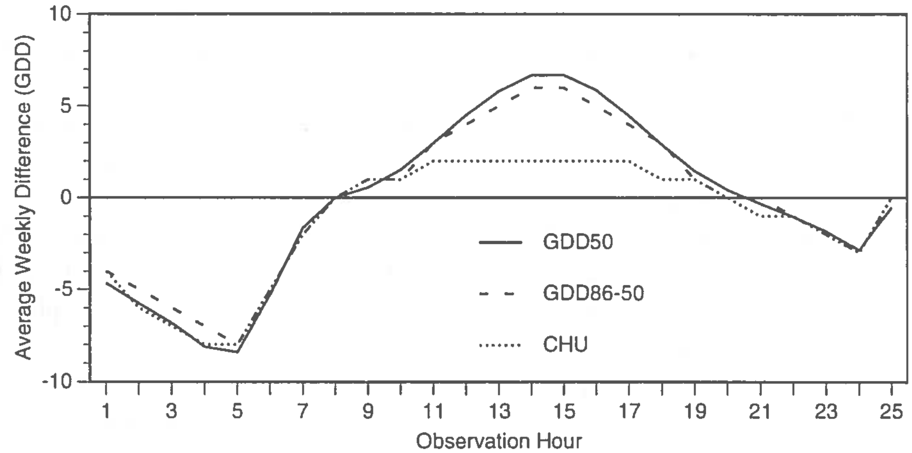

Figure 1. Average weekly observation time bias from an 0800 observation for each hour during July for GDD50 (solid line), GDD86-50 (dashed line) and CHU (dotted line). Hour 25 corresponds to the Canadian observation method.

Observing and reporting practices often differ across national borders. In Canada, daily temperature observations are taken twice daily, once in the early morning and again during the late afternoon or early evening. After each observation, thermometers are reset yielding two sets of maximum and minimum temperatures during each day. Using these observations, the daily maximum temperature for day n is defined as the warmer of the afternoon maximum temperature of day n and the morning maximum temperature of day n+1. Daily minimum temperature is simply the colder of the morning and afternoon minimum temperatures of day n. An advantage to this observation practice is that the reporting date of maximum and minimum temperatures generally corresponds to their actual date of occurrence.

EFFECTS OF OBSERVATION TIME BIAS

In addition to affecting seasonal GDD totals, observation time bias also affects the dates on which key GDD totals reach significant threshold values during the growing season. These threshold accumulations are used in predicting crop development stages, selecting appropriate crop varieties for a given area and the application of chemical pest and weed controls. Figure 2 illustrates the typical effect of observation time bias and Canadian observing practice on GDD50 accumulations using data from Atlantic City, NJ during 1986. Due to the warm bias associated with an afternoon observation time, GDD using a 1600 observation schedule accumulate at a faster rate than those associated with other observation hours. The effect of OTB is exaggerated early in the season since some days which accumulate GDD based on a 1600 observation, do not gain any GDD using 0600 temperature observations. In this example a 110 GDD threshold, corresponding to the emergence of the tarnished plant bug, would be met before 7 April using the 1600 observation. Based on a 0600 observation, however, this GDD total is not reached until late in the week ending 30 April. The Canadian observation practice produces GDD accumulations that fall between the extremes associated with the two U.S. observation hours.

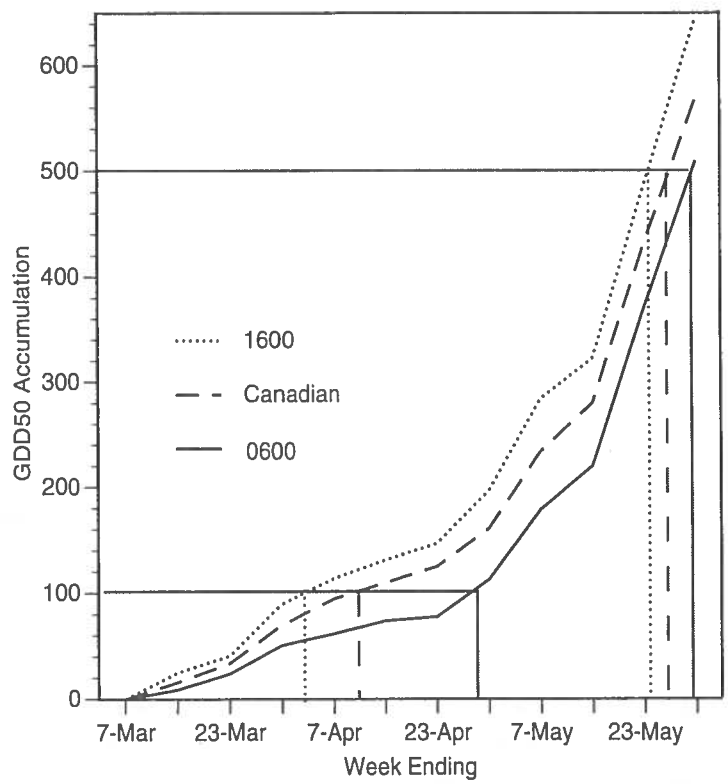

Figure 2. Cumulative weekly GDD50 accumulations during 1986 at Atlantic City, NJ based on an early morning (0600) and late afternoon (1600) observation time and the Canadian method of temperature observation.

Later in the growing season, a relatively high number of GDD accumulate for all observations hours. Therefore, the difference between the dates on which a 500 GDD threshold is reached narrows to about a week (Fig. 2). This threshold corresponds to the emergence of the growth point of corn plants. However, because the effect of OTB is cumulative, this difference increases as the growing season progresses. For instance, when data from Buffalo, NY were used to calculate GDD86-50 values associated with different observation times and methods, a difference of approximately 4 days existed between the occurrence of 500 GDD86-50 using a 1600 and 0600 observation time. By the week ending 23 July, a 1300 GDD86-50 threshold was met using GDD derived from the 1600 observation. However, based on 0600 temperature observations, this GDD milestone for silking of corn plants was not reached until the end of the following week. By harvest, the time required to reach a 2300 GDD86-50 threshold differed between the two observation times by over three weeks. The Canadian observation method yielded GDD which accumulate at an intermediate rate as compared to the U.S. 0600 and 1600 observations throughout the growing season.

DEVELOPMENT OF ADJUSTMENT FACTORS

Adjustment factors representing the average difference between the weekly GDD accumulation for a given hour and that of an 0800 observation schedule are used as a basis for standardization. An 0800 observation was chosen as the standard because temperature observations are most commonly taken during the morning in the Northeast and therefore this hour would introduce minimal change to the GDD threshold values that are in common use.

During the spring (March–May) and autumn (September–November), the magnitude of the adjustment factors during individual weeks is dependent upon the number of days which contribute to the weekly GDD total since no observation time bias (OTB) can occur on days when no GDD accumulate. During weeks with a low GDD total, the number of days with no GDD is likely to be high, leading to a reduction in the OTB for the week. Weeks with a high GDD total have few, if any, days that fail to accumulate GDD resulting in a relatively high observation time bias. Our analysis indicates that improved accuracy results when different adjustment factors are applied for weeks that accumulate more or less than 25 GDD.

In the summer months (June–August), OTB is reduced during weeks in which the mean temperature exhibits little day-to-day variability. This occurs because even if the maximum or minimum temperature of a given day occurs at observation time and becomes the extreme temperature for two 24-hour periods, this value will be similar to that based on any other 24-hour period. Conversely, weeks which experience considerable day-to-day variability in mean temperature are generally characterized by relatively high values of OTB. During these months different adjustment curves must be used depending on whether or not the average difference in daily mean temperature exceeds 2°F.

GDD totals based on observations taken prior to the time of normal maximum temperature occurrence are subject to additional inconsistencies. In these cases the maximum temperature reported for a day generally occurs during the preceding day. This often leads to an 0800 GDD calculation for the first day of a week incorporating the maximum temperature that was used to calculate an afternoon GDD value during the last day of the previous week. Therefore, prior to adjustment, steps must be taken to assure that the day on which a maximum temperature is reported by an afternoon observer corresponds to the day on which an 0800 observer would have reported the same maximum temperature.

APPLICATION OF ADJUSTMENT PROCEDURE

The standardization of a weekly GDD total for a daily observing site is accomplished using the following procedure:

1. Determine the hour at which the daily maximum and minimum temperature observations are taken.
2. If the observation hour is later than 1400, reassign the maximum temperature reported on day n to the maximum temperature value for day n+1. For example, assume the values in Table 1 represent the maximum temperatures from a 1600 temperature observation. The daily maximum temperatures should be reassigned as shown in the table. Once this reassignment has been accomplished, recalculate the GDD total for the week.

Table 1. Example of the reassignment of maximum temperature observations based on a 1600 observing schedule.

Date	Reported Max. Temp.	Reassigned Max. Temp.
May 31	80°	
June 1	85°	80°
June 2	90°	85°
June 3	75°	90°

3. During the summer months calculate the average day-to-day mean temperature difference, T_D using the following formula:

$$T_D = \frac{1}{n}\left\{\sum_{i=1}^{n} \left| T_{mean_i} - T_{mean_{i-1}} \right| \right\}$$

where n is the number of days in the week (7); i is the day of the week and T_{mean} is the mean daily temperature.

4. Determine the value of the index, j. During the summer (June–August), j = 1 if $T_D \leq 2°F$ otherwise j = 2. During the spring (March–May) and autumn (September–November), j = 1 if the weekly accumulation of GDD is less than 25. In all other cases j = 2.

5. Use Table 2 for GDD50, Table 3 for GDD86-50 or Table 4 for CHU to obtain the weekly adjustment factor associated with the appropriate month, observation hour and j value.

6. Standardize the weekly GDD accumulation using the following formula:

$$GDD_{8m} = GDD_{hm} - C(h,m,j)$$

where GDD represents the weekly GDD accumulation and C is the adjustment factor for observation hour h, month m and the appropriate j value. As an example, suppose 200 GDD50 accumulated during the first week in June at a site with a 1500 observation schedule. Assuming the average day-to-day mean temperature difference during this week was 5°F, the appropriate adjustment factor, C(h,m,j), given in Table 2 is 9 GDD. Applying this adjustment gives a standardized GDD total of 191 GDD.

RESULTS OF STANDARDIZATION

Figure 3 illustrates the typical reduction in average OTB as a result of standardization. The average OTB before standardization is also shown. Similar results are obtained for other months and when using GDD86-50 and CHU. By minimizing the OTB in individual weekly GDD totals, the standardized values for each hour accumulate at very nearly the same

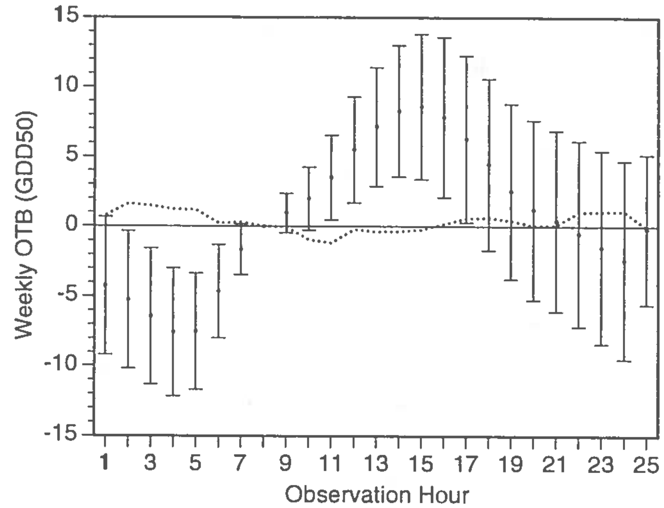

Figure 3. Average weekly GDD50 OTB during June before adjustment (closed circles). Vertical bars denote a ±1 standard deviation interval about the mean OTB. The residual OTB after standardization is also indicated by the dotted curve. Values indicated for hour 25 correspond to Canadian observation practices.

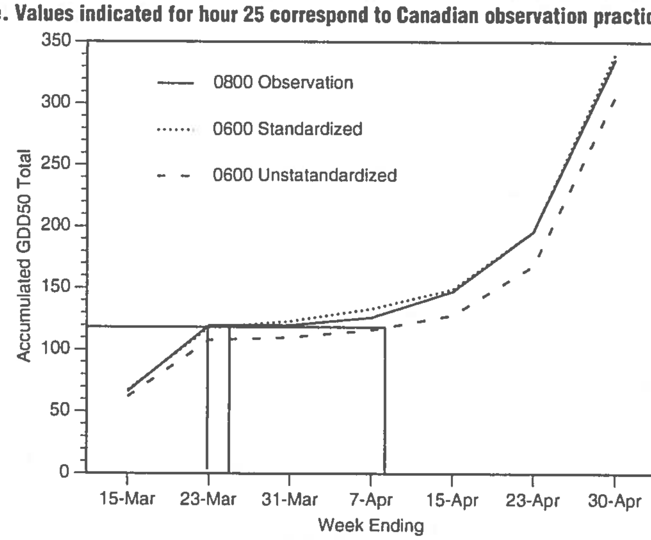

Figure 4. Comparison of weekly GDD50 accumulations during March–April 1989 at Baltimore, MD. Accumulations for standardized and unstandardized 0600 temperature observations are shown along with the accumulation for observations taken at 0800.

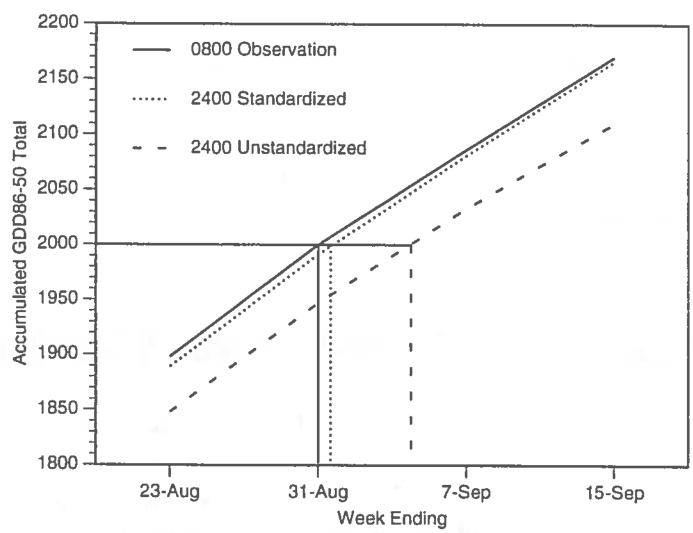

Figure 5. Weekly GDD86-50 accumulations during 1988 at Massena, NY comparing an unstandardized midnight temperature observation (dashed) with the standardized (dotted) and 0800 (solid) values.

rate throughout the growing season. Figure 4 illustrates the benefit of using the standardization procedure for weekly GDD50 accumulations during the early spring of 1989 at Baltimore, MD. Unadjusted 0600 observation GDD totals accumulate at a much slower rate than those calculated from 0800 temperature observations. After standardization both the 0600 and 0800 GDD totals accumulate at approximately equal rates. In Figure 5, the weekly increase in accumulated GDD86-50 is shown for the latter part of the 1988 growing season at Massena, NY. Without standardization, midnight observations accumulated about 70 fewer GDD than would have accumulated based on an 0800 observation through the end of August. After adjustment, both the 0800 and standardized midnight GDD accumulations reach the 2000 GDD threshold on approximately the same date. Results similar to those shown in Figures 4 and 5 are also achieved using CHU.

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Table 2. Weekly adjustment factors, C(h,m,j), for GDD50. During the summer, the appropriate value of j depends upon the average day-to-day temperature difference, T_D. If $T_D \leq 2°F$, j = 1, otherwise j = 2. During the spring and autumn, j = 1 if the weekly accumulation of GDD is less than 25. In all other cases j = 2. Hour 25 represents adjustment factors for the Canadian observation method.

	SPRING						SUMMER						AUTUMN					
	Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov	
Hour	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2
1	-1	-3	-2	-4	-5	-6	-5	-5	-4	-5	-3	-4	-3	-3	-2	-2	0	1
2	-2	-4	-3	-5	-6	-7	-6	-7	-4	-6	-3	-6	-3	-4	-2	-3	0	0
3	-2	-4	-3	-5	-6	-8	-7	-8	-5	-7	-4	-7	-4	-5	-2	-4	0	-1
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5	-2	-5	-4	-7	-7	-9	-6	-9	-7	-9	-6	-9	-5	-7	-3	-5	-1	-2
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24	-2	-2	-2	-3	-6	-3	-2	-4	-2	-3	-2	-4	-1	-3	-2	-2	-2	-2
25	0	-1	0	0	-3	-3	-1	0	-1	-1	-1	1	2	2	1	2	1	4

Table 3. Weekly adjustment factors, C(h,m,j), for GDD86-50. During the summer, the appropriate value of j depends upon the average day-to-day temperature difference, T_D. If $T_D \leq 2°F$, j = 1, otherwise j = 2. During the spring and autumn, j = 1 if the weekly accumulation of GDD is less than 25. In all other cases j = 2. Hour 25 represents adjustment factors for the Canadian observation method.

	SPRING						SUMMER						AUTUMN					
	Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov	
Hour	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2	j=1	j=2
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24	0	0	0	0	-1	-1	-2	-3	-2	-3	-2	-4	-2	-2	-2	0	0	2
25	0	0	0	0	-1	-1	-1	0	-1	0	0	1	1	1	0	1	0	1

Table 4. Weekly adjustment factors, C(h,m,j), for CHU. During the summer, the appropriate value of j depends upon the average day-to-day temperature difference, T_D. If $T_D \leq 2°F$, j = 1, otherwise j = 2. During the spring and autumn, j = 1 if the weekly accumulation of CHU is less than 25. In all other cases j = 2. Hour 25 represents adjustment factors for the Canadian observation method.

	SPRING						SUMMER						AUTUMN					
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19	1	4	1	4	3	3	2	2	1	1	0	1	3	3	3	4	1	5
20	1	3	1	3	1	1	1	1	0	0	0	0	1	1	2	3	1	3
21	0	2	1	2	0	0	1	0	-1	-1	-1	-1	0	0	2	2	1	3
22	0	1	0	1	-1	-1	0	-2	-1	-1	-1	-2	-1	-1	2	1	1	2
23	0	0	0	0	-2	-2	-1	-3	-1	-2	-1	-3	-2	-2	1	0	0	2
24	0	-1	0	-1	-3	-3	-2	-4	-2	-3	-2	-4	-3	-3	1	-1	0	1
25	0	0	0	0	-1	-1	-1	0	-1	0	0	1	2	2	0	3	1	3

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