Selection of images for METRIC processing for the Flathead Indian Reservation, Montana
By J. Kjaersgaard and R. Allen, University of Idaho. July 2008.

Introduction and image selection criteria
This note describes the procedure for selecting Landsat satellite images to be processed using the METRIC ET procedure for the Flathead Indian Reservation, Montana. For this application, images from the Landsat 5 and Landsat 7 satellites are utilized due to their band combinations and high resolution. The image archive for Landsat 5 dates back to 1984 and the satellite is still in operation. Landsat 7 was launched in 1999, but the scan line corrector failed in May 2003 resulting in subsequent images having wedge shaped stripes of missing data across the scenes. There is no information contained in the stripes.

The Flathead Indian Reservation is conveniently contained in one scene path/row, i.e. path 41, row 27. A total of nine images are to be selected for processing, which includes the seven images from the contract and two additional images from early and late season, respectively, that the UI will process for gratis. The images should be distributed as evenly as possible throughout the growing season with preferably no more than 32 days between images.

The most important criteria for the image selection are an assessment of the atmospheric conditions at the time of the satellite overpass. The occurrence of conditions impeding the clearness of the atmosphere, such as clouds (including thin cirrus clouds and jet contrails), smoke, haze and similar over the study area may render an image unusable for processing in METRIC. Even very thin cirrus clouds have a much lower surface temperature than the ground surface and since METRIC needs surface temperature estimates to solve the energy balance, areas with cloud cover cannot be processed. In addition, in cases of partial cloud cover, land areas recently covered by clouds may be cooler as they have not yet reached a thermal equilibrium corresponding to the energy loading from the sun will also have to be masked out.

Since one of the project goals is to study water distribution and use by irrigated agriculture it is probably desirable not to select a wet year, as this may partly blur the differences in crop water use between fields.

To aid the selection of images an image rating system has been employed where the usability of an image in terms of cloudiness and smoke is ranked as a fraction on a scale between "0" and "1", where "0" is an unusable image (e.g. complete cloud cover) and "1" is a nice, usable image. If an image has partial cloud cover over the study area it is rated accordingly, e.g. if an estimated 70 % of the study area is cloud and cloud shadow free, it may be rated 0.7.

A graphical representation of the rating for path 41, row 27 for the period January 1997 to July 2008 is shown in Fig 1. Images are assessed using the USGS on-line image preview tool glovis at http://glovis.usgs.gov/.

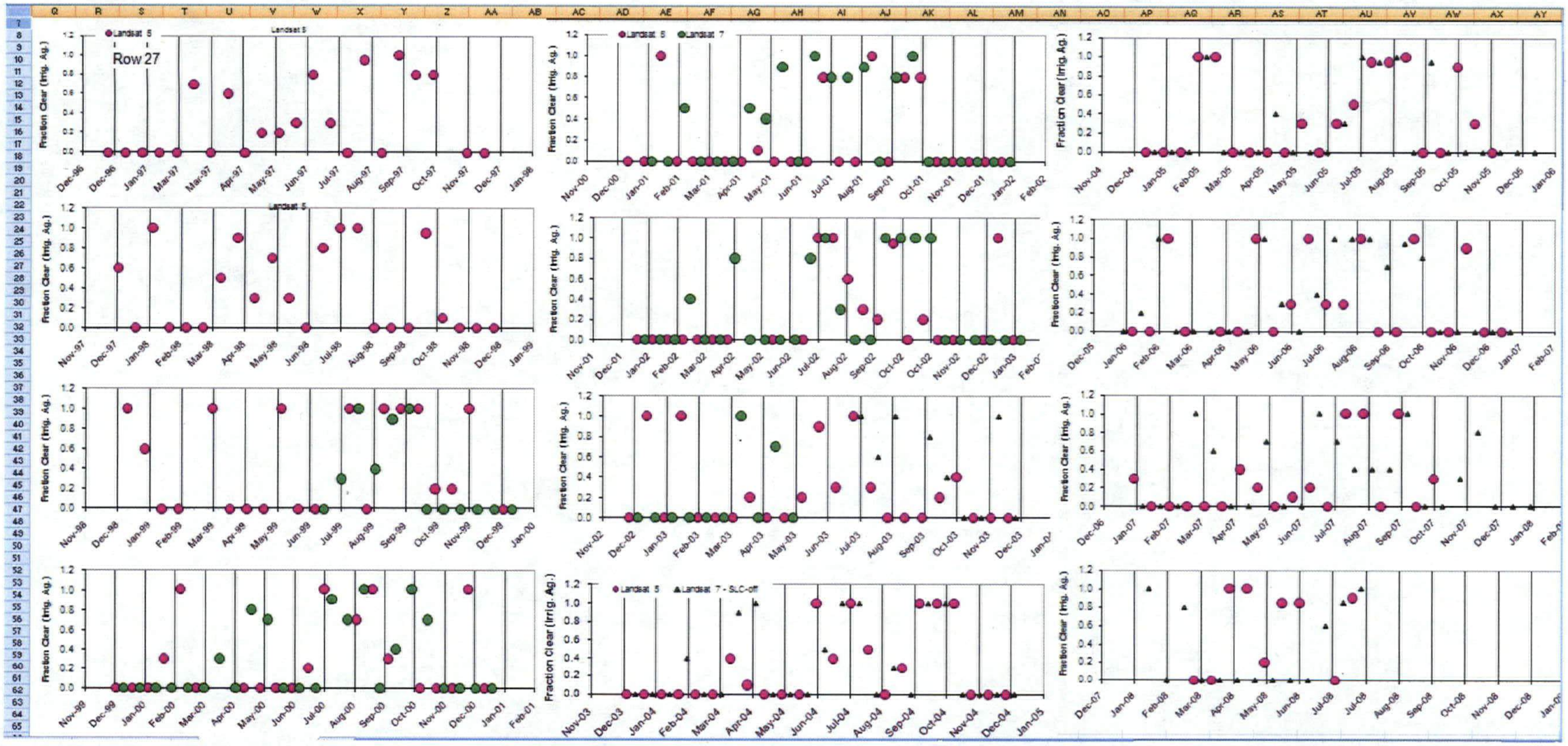

Fig 1. Graphical representation of the image ratings between January 1997 and July 2008. Pink circles are Landsat 5, green circles are Landsat 7 (SLC-on) and triangles are Landsat 7 (SLC-off).

Seasonal ET estimations aggregated using images from multiple years

None of the years 1998 – 2008 have a complete coverage of good cloud free images throughout the year. It is particularly important to have good, cloud free images during the spring and early summer, as the shape of curve used to define the temporal development of ET is somewhat variable depending on crop type and crop management during this period. Unfortunately, the Flathead valley has very few cloud free days during this period (April to early June) for nearly all years of record.

In addition, images from Landsat 7 (SLC-off) are generally less suited for the METRIC processing, as portions of the image contain no data. Even though the study area is located towards the center of the image, some parts will be covered by blank spots. Due to the temporal spacing between images, it is difficult to fill these gaps, resulting in "holes" when ET calculated from each image is aggregated to monthly and seasonal ET. Information must therefore be interpolated from adjacent image dates, which causes some loss in developmental information on ET.

To get a complete coverage over a full growing season, we have therefore identified a "base" year and have used images from other years to fill in holes in the image sequence. This approach is feasible since the cropping patterns in western Montana tend to stay relatively constant between years, not least for the less-intensive cropping systems consisting of grass or grass/alfalfa mix for hay or forage.

For the high intensity cropping systems using a crop rotation between years, this approach will result in some error for individual fields that may have experienced crop rotation. However, since the crop rotation pattern is assumed to stay relatively constant, year to year in regard to total acreages of a particular crop, any biases in the ET estimations arising from different crop types for the same field at different years should cancel when ET is aggregated over a large number of fields.

To evaluate and account for climatic variation among years, the cumulative number of Growing Degree Days (GDD) have been calculated for each year 1998 - 2008 based on temperature information from the St. Ignatius and Round Butte Agrimet weather stations. GDD is calculated as

$$GDD = (T_{min} + T_{max})/2 - T_{base} \qquad (1)$$

where T_{min} and T_{max} are daily minimum and maximum air temperature, respectively, and T_{base} is a "base" temperature below which none or very little plant development occurs. T_{max} is often capped at a threshold temperature, above which higher temperature are not beneficial for plant growth.

Commonly used thresholds for Eq. 1 are T_{base} = 10 °C and T_{max} capped at 30 °C. GDDs reported from the Agrimet network are based on these thresholds and are appropriate for corn and crops requiring relatively high temperatures for their development. For alfalfa, small grain cereals and (cool season) grass, T_{base} values between 0 and 5 are more appropriate. Due to the relatively short growing season caused by low temperatures in the spring and fall, the Flathead area is dominated by hay and forage C_3 grasses, alfalfa and small grains. Hence, a T_{base} = 0 °C and a T_{max} threshold of 30 °C were used to calculate GDD. The accumulation of GDD was initiated on April 1 (March 30 for leap years). Cumulative GDD for each year in the period January 1998 - June 2008 from St. Ignatius and Round Butte are shown in Figures 2 and 3. The difference from the mean is shown in Figures 4 and 5.

The GDDs have been used to identify images compatible to the base year and, if needed, to adjust an image date to match the approximate crop growth stage relative to the base year.

Additionally, to avoid sampling too large of differences in the vigor and ET from non-irrigated vegetation between compatible years due to differences in precipitation, we have compared precipitation patterns among years. The annual average precipitation measured at the St. Ignatius and Round Butte weather stations are shown in Figure 6 and annual cumulative precipitation is shown in Figures 7 and 8. The differences in annual precipitation between stations may be caused by the precipitation gradient across the Flathead valley and possibly more turbulence in the airflows around the Round Butte station caused by nearby obstructions (tall bush-like vegetation, trees, buildings) compared to the airport location of the St Ignatius station.

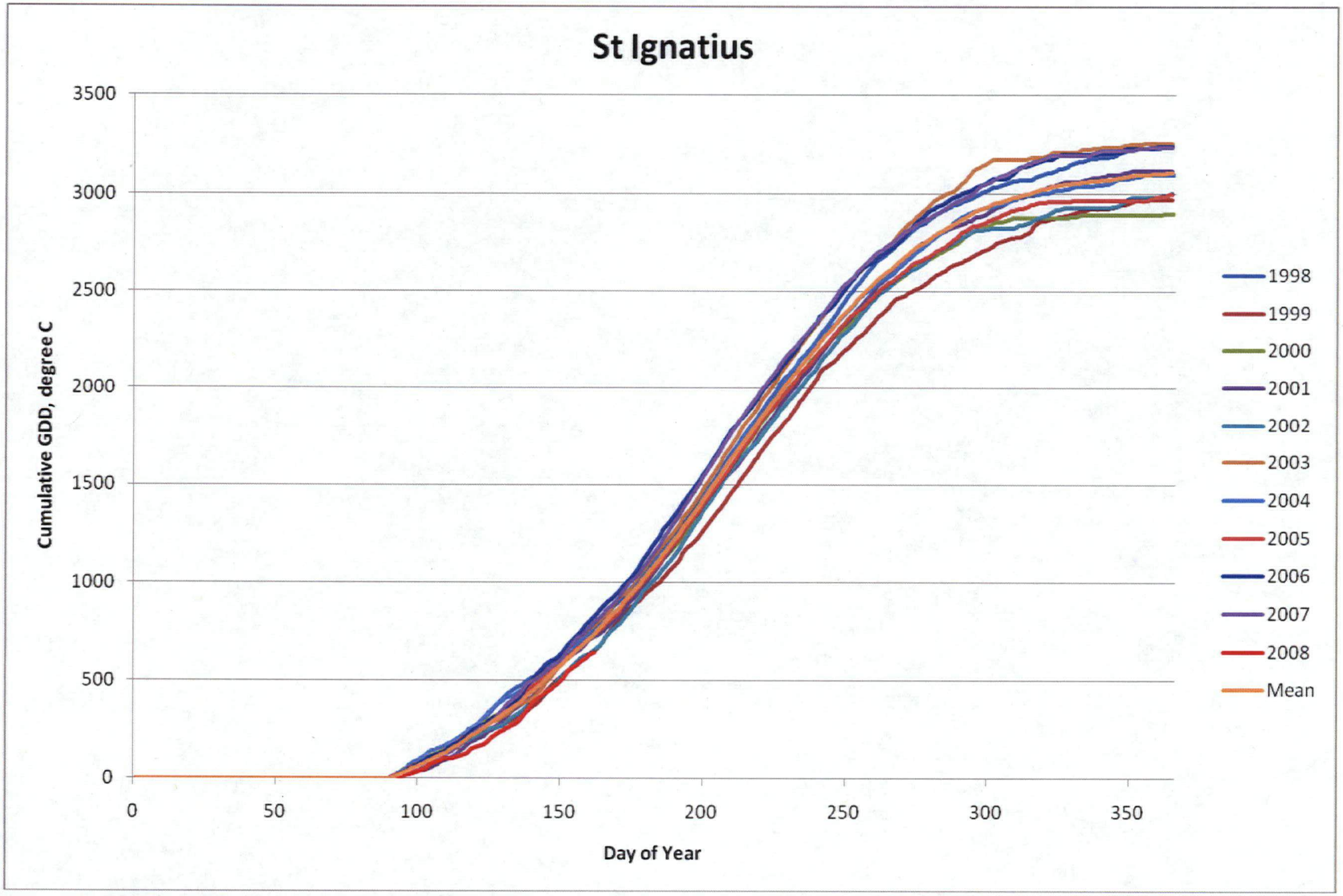

Fig 2. Cumulative Growing Degree Days (GDD) based on the St. Ignatius Agrimet weather station.

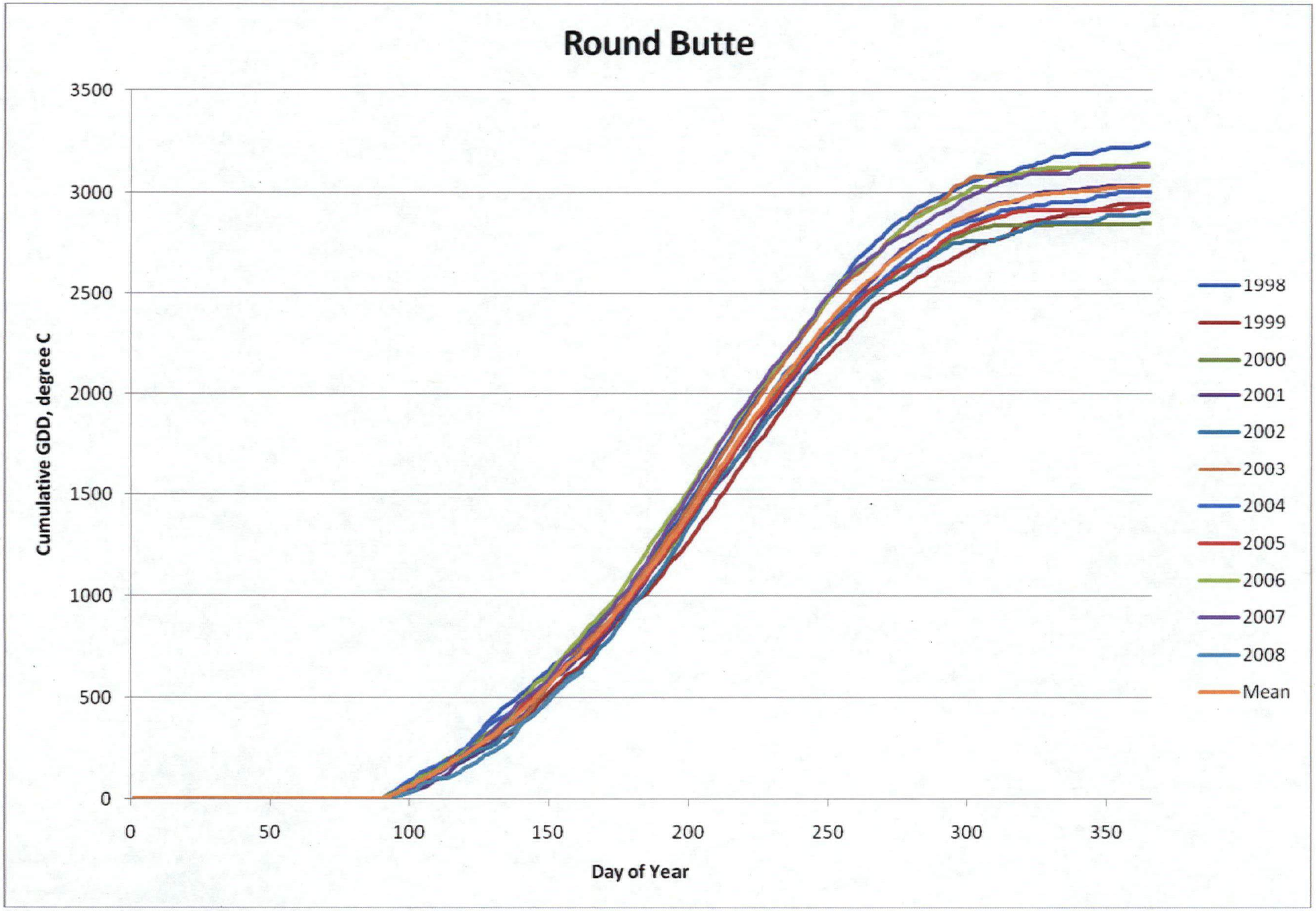

Fig 3. Cumulative Growing Degree Days (GDD) based on the Round Butte Agrimet weather station.

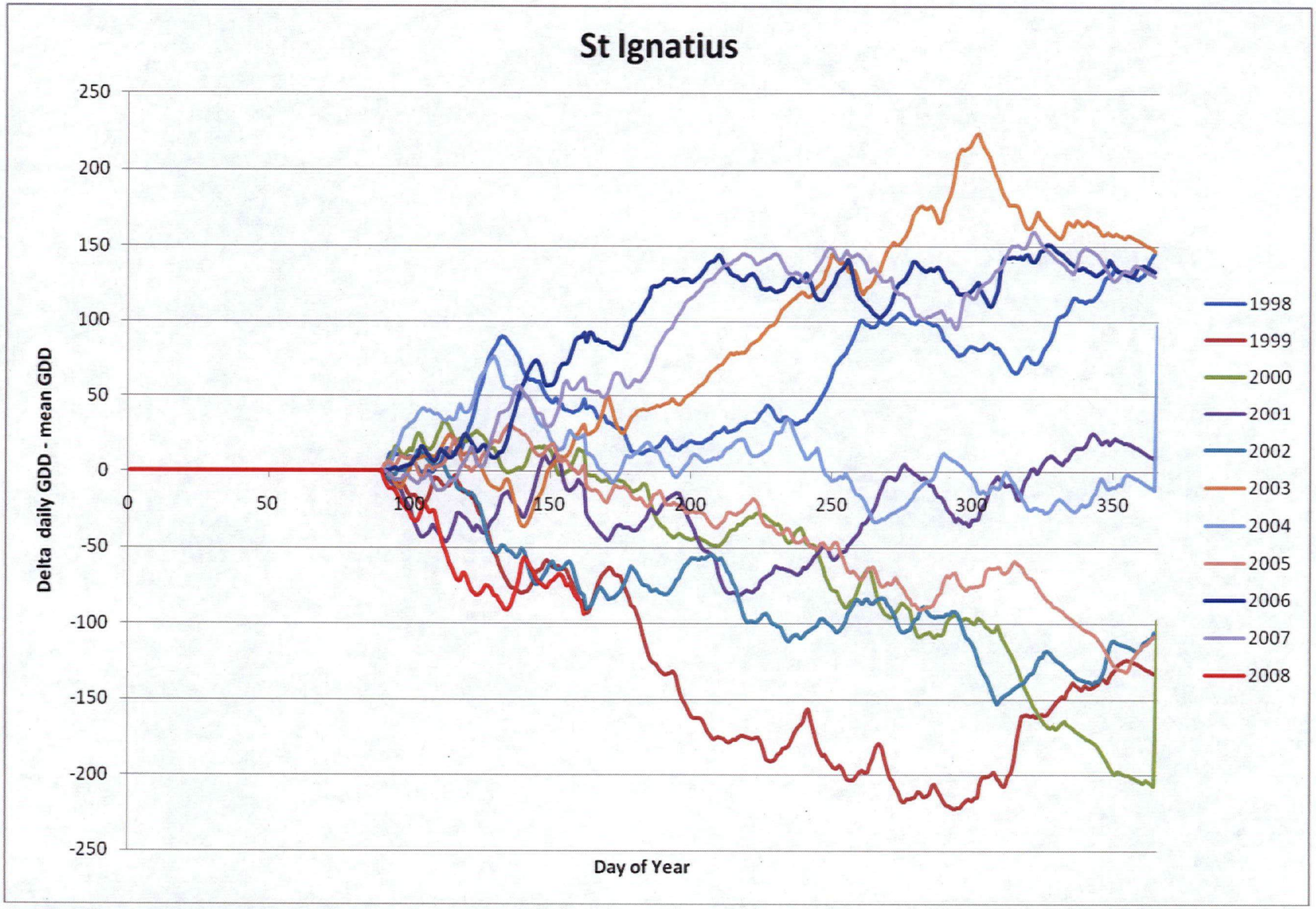

Fig 4. Difference between daily Growing Degree Day (GDD) per year and mean GDD over all 11 years calculated from the St. Ignatius Agrimet weather station. Degrees in °C.

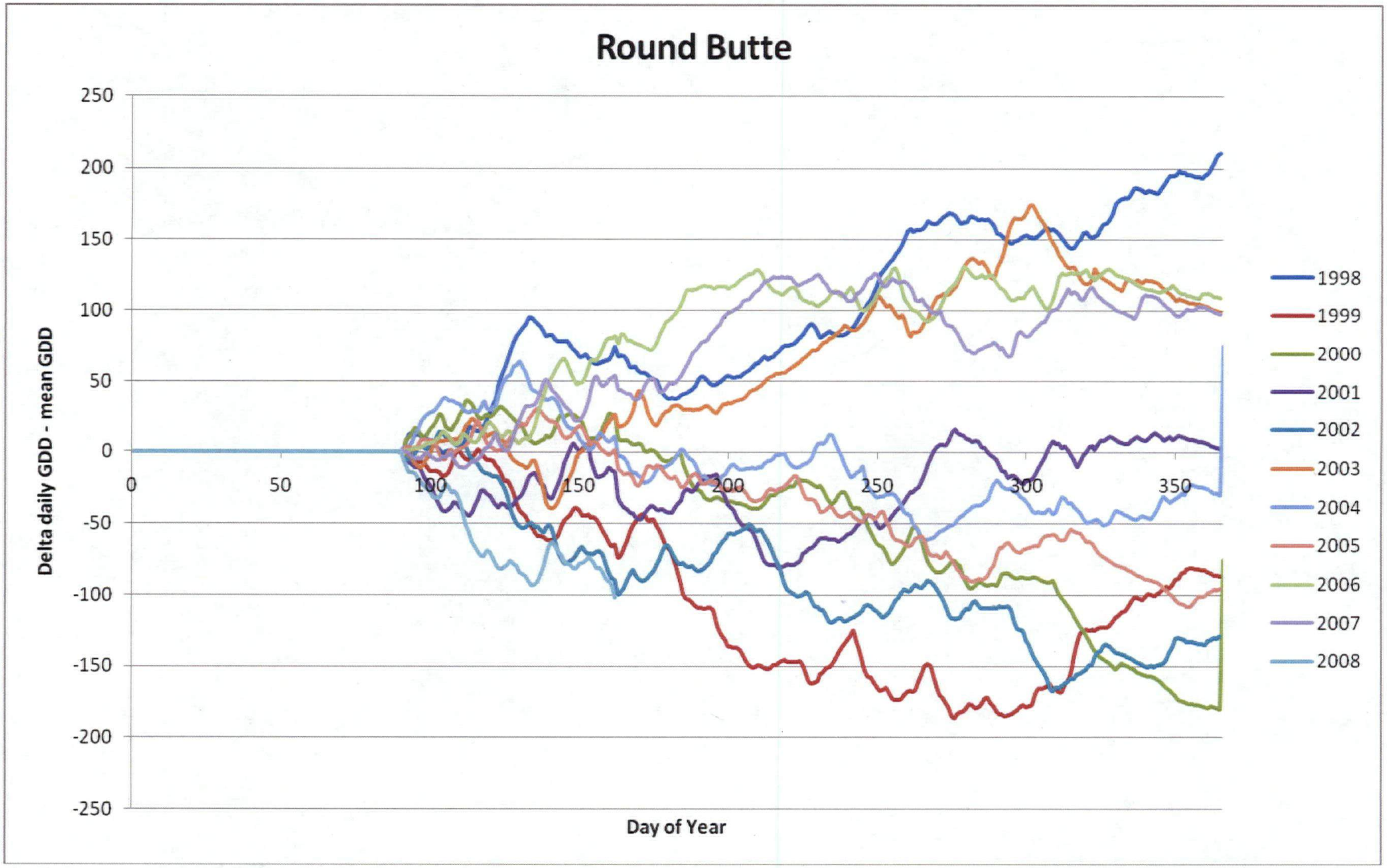

Fig 5. Difference between daily Growing Degree Day (GDD) per year and mean GDD over all 11 years calculated from the Round Butte Agrimet weather station. Degrees in °C.

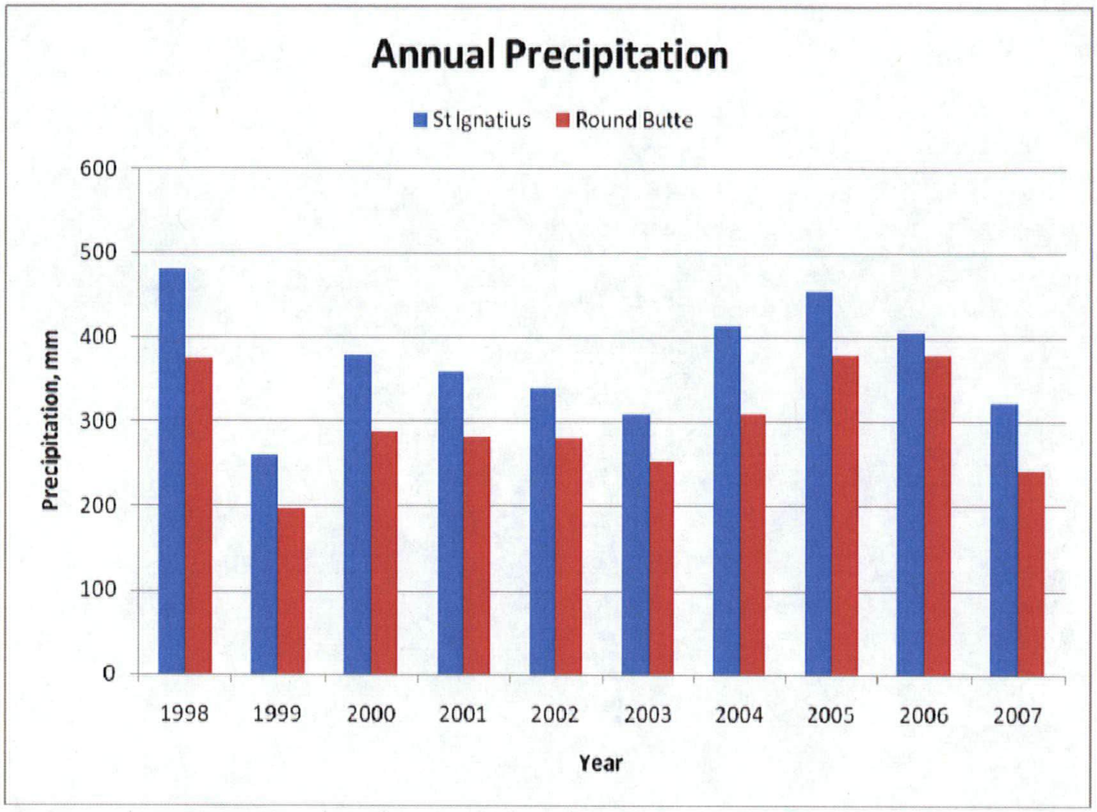

Fig 6. Annual precipitation (mm) recorded at the St Ignatius and Round Butte Agrimet weather stations

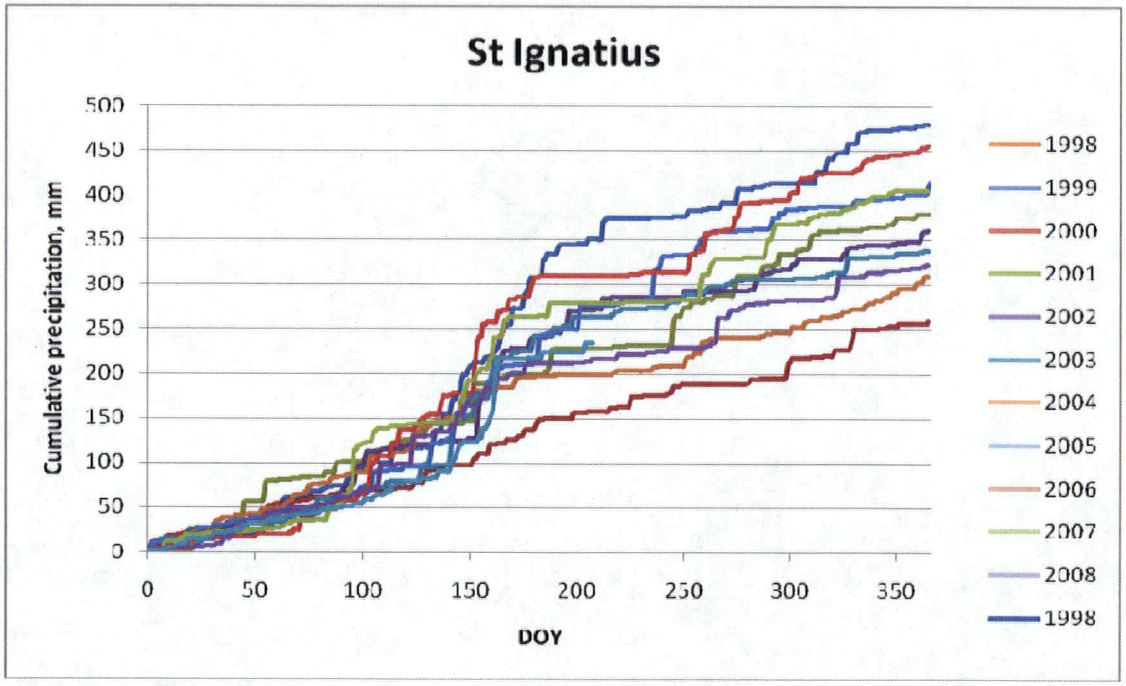

Fig 7. Cumulative daily precipitation measured at the St Ignatius Agrimet weather station.

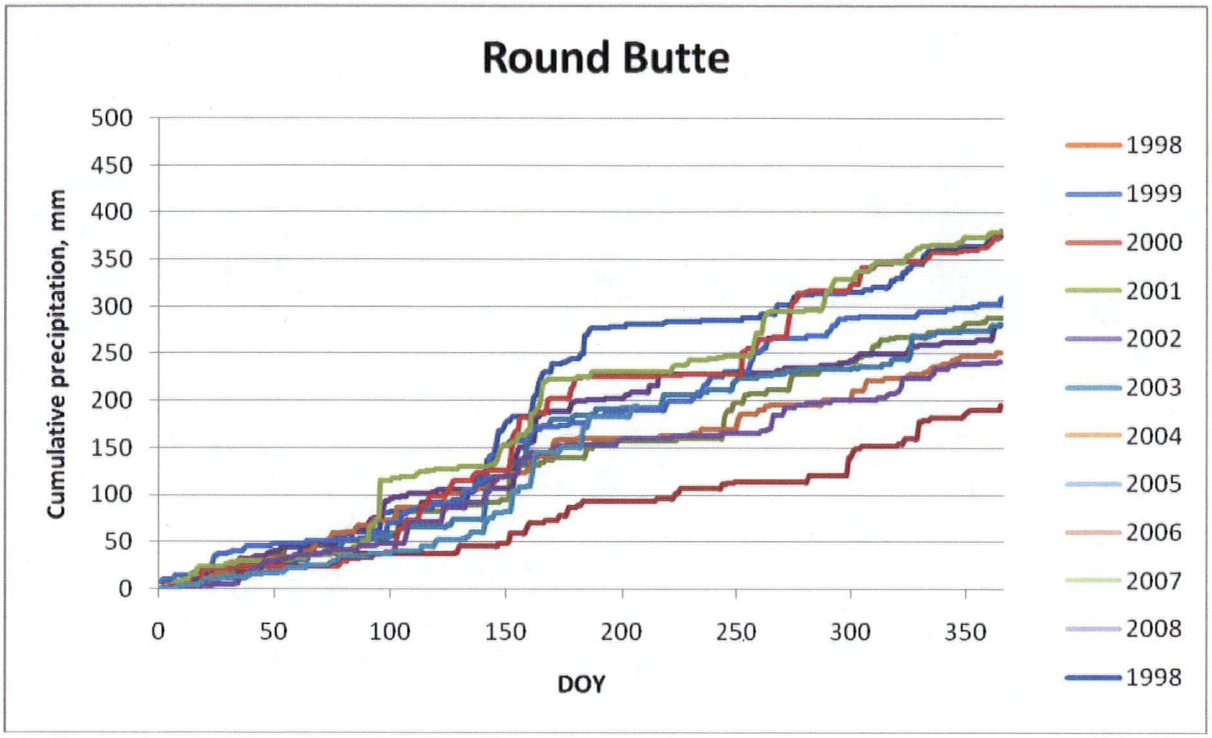

Fig 8. Cumulative daily precipitation measured at the Round Butte Agrimet weather station.

Image selection

Based on the criteria and information discussed above, two sets of possible image dates have been identified, as summarized in tables 1 and 2. Year 2002 is used a base year for option A in table 1, while year 2006 is used a base year for option B in table 2. As seen from Figures 4 and 5, 2002 was cooler than average for the 10-year period, while 2006 was warmer than the 10-year period.

For years other than the base year, the fourth column in tables 1 and 2 indicates which date in the base year the same GDD on the image date was reached. Differences between the first and fourth columns indicate how much the vegetation development in the non-base year image date may be advanced or retarded relative to the base year. The GDDs are based on the Round Butte weather station.

Table 1. Possible image dates for METRIC processing, option A. Suggested image dates are highlighted in yellow.

Image date	Year	Satellite	GDD date* Base=2002	Comments
Feb 19	00	L5	n/a	
Mar 20	99	L5	n/a	
Apr 8	03	L7	Apr 6	Not much green on fields
May 10	06	L5	May 16	Late year (06 vs. 99-03 for the rest of the images)
May 20	01	L7	May 23	Rating: 0.9 few cumulus over agric areas
May 23	99	L5	May 24	
Jun 21	01	L7	Jun 23	
July 2	02	L5		
July 10	02	L7		
July 12	00	L5	Jul 14	
July 18	02	L5		Maybe some smoke in N part
July 26	99	L5	July 21	
Aug 3	99	L7	July 29	
Aug 16	01	L5	Aug 18	
Aug 21	00	L7	Aug 26	
Aug 29	00	L5	Sep 2	
Sep 12	02	L7		
Sep 28	02	L7		
Oct 8	00	L7	Oct 10	Still some green on fields
Oct 14	02	L7		Smoke?
Oct 30	02	L7		Snow in SW part of valley – very little green on fields
Dec 3	00	L7	Nov 21	

*Corresponding date in 2002 based on GDD, i.e. which date in 2002 reached the GDD as this date in year X (example: the GDD on Apr 8 2003 = 50.3; in 2002, this GDD value was reached on Apr 6).

Table 2. Possible image dates for METRIC processing, option B. Suggested image dates are highlighted in yellow.

Image date	Year	Satellite	GDD date* Base=2006	Comments
Feb 19	06	L5	n/a	
Mar 4	05	L5	n/a	
Mar 28	08	L5	n/a	
Apr 8	03	L5	Apr 6	
Apr 13	08	L5	Apr 9	Very little green in agric area
May 10	06	L5		
May 18	06	L7		Note: Landsat 7 SLC-off
May 31	08	L5	May 22	Few cumulus, agric area cloud free
Jun 21	04	L5	Jun 15	
Jun 27	06	L5		
Jul 16	07	L5	Jul 14	
Jul 21	03	L5	Jul 17	
Aug 1	07	L5	Aug 1	
Aug 14	06	L5		
Aug 27	05	L5	Aug 18	
Sep 2	07	L5	Sep 2	
Oct 1	06	L5		
Oct 27	04	L5	Oct 6	

*Corresponding date in 2006 based on GDD, i.e. which date in 2006 reached the GDD as this date in year X (example: the GDD on Apr 8 2003 = 50.3; in 2006, this GDD value was reached on Apr 6).