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Jupiter's Changing North Equatorial Belt

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ABSTRACT

New monthly latitude measurements of the northern and southern boundaries of Jupiter's North Equatorial Belt (NEB) are reported for 1995 to 2011. The latitudinal width oscillated with a period of about 4½ years during this time. This is similar to the behavior between 1896 and 1953 as reported in the literature. One new finding is that the width changed over a few months. The barge, a dark and almost rectangular-shaped spot, is the most well observed feature in the NEB. It was decided to investigate what affect the changing NEB had on the number and drift rate of barges. There is little correlation between belt width and the number of NEB barges. There is also little correlation between belt width and the average drift rate of NEB barges.

Key Words: Jupiter, Jupiter's North Equatorial Belt, belt width

INTRODUCTION

Jupiter has undergone many changes in recent years. Some of these include the disappearance and reappearance of the South Equatorial Belt in 2010 (1-3), the appearance of barges in the North Equatorial Belt (2-14) and the development of the South Temperate Belt-North Jetstream (2-3, 15). One feature that changes frequently is the width of Jupiter's North Equatorial Belt (hereafter NEB). Two questions are: Does one change cause a second change? Does the NEB width impact barge characteristics? Answers to these questions may give us a better understanding of Jupiter's meteorology.

Both professional and amateur astronomers have recorded images of Jupiter for over two hundred years. Before the early 20th century, these images were in the form of drawings. Afterwards, they were a mixture of drawings, photographs and digital images. The record of Jupiter images has been almost continuous since the late 19th century. Lowell Observatory and other observatories also have photographs of Jupiter dating back to the early 20th century. The Association of Lunar and Planetary Observers has Jupiter images dating from 1948 up to the present. Members of this organization post hundreds of Jupiter images on several websites and also send them to the writer for analysis. One person who submitted recent images is Trevor Barry; two of his images are in Figure 1.

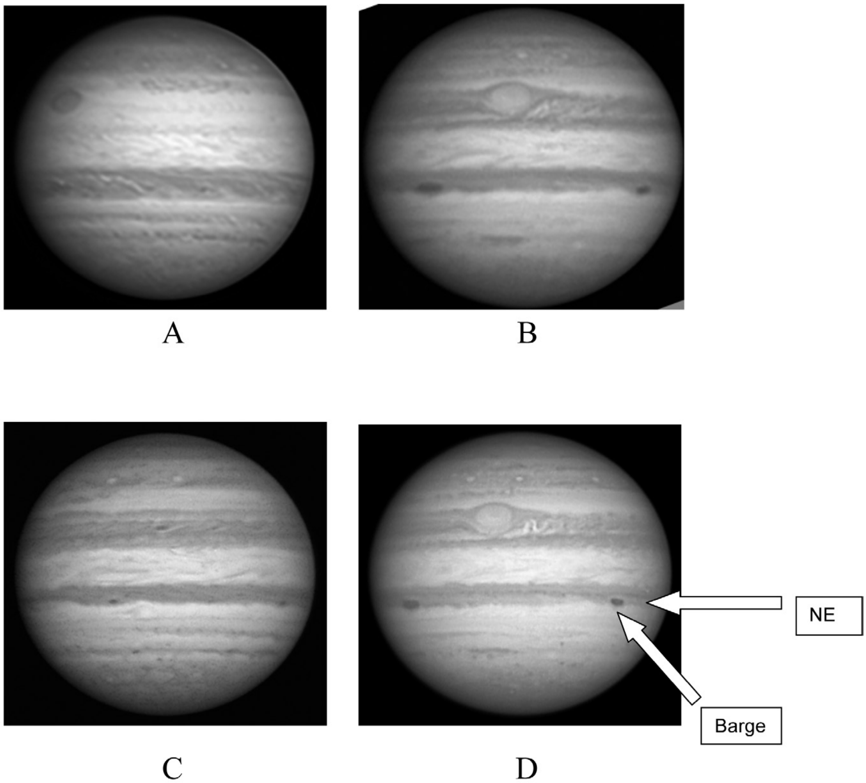

Figure 1. Images of Jupiter. A) July 1, 2010 (18:10 UT) by Trevor Barry; B) September 21, 2011 (16:51 UT) by Trevor Barry; C) October 6, 2011 (1:28 UT) by Rich Jakiel; D) October 6, 2011 (0:19 UT) by Cristian Fattinnanzi. Note that the NEB is thinner at some longitudes than at others. South is at the top in all images. The NEB and a barge are labeled with arrows.

The NEB has undergone width changes during the last 120 years (2-14, 16-17). Based on (18), the NEB width doubled between 1943 and 1946. It also changed by a similar amount between 1920 and 1921 (16). More recently, Trevor Barry recorded a width change between 2010 and 2011. See Figures 1A and 1B. One problem with the previous NEB width studies is that only annual averages are reported. Another possible problem is that it is not clear how width variations at different longitudes are handled. The NEB width can change with longitude and this can be a factor in NEB width studies. See Figures 1C and 1D. This second problem underscores the importance of measuring the width at several longitudes and taking an average.

Barges are dark and have an almost rectangular shape. They typically last for several months but may last over a year. Both John Rogers of the British Astronomical Association and the writer have measured drift rates for these features for several years. The drift rate is the change in system II longitude in 30 days. For example, if a barge's longitude increases by 15 degrees in 150 days, its drift rate would be +3°/30 days. The drift rate is positive if the longitude increases or moves westward with time; otherwise it is negative. Barge drift rates since 1995 have almost always been between -5°/30 days and + 5°/30 days.

The writer has several goals in this study. One of these is to investigate the time period between maximum NEB widths since 1995. A second goal is to establish the length of time for a width change. For this reason, monthly measurements are reported. Another reason for carrying out this work is to determine whether width changes happen at regular time intervals. Finally, the correlation between belt width and barge characteristics is determined.

METHOD AND MATERIALS

One may measure the width of the NEB directly without measuring latitude. There are, however, two limitations to doing this. Firstly, a belt width in a two-dimensional image cannot yield the width without latitude data. Essentially a belt that is 0.10 polar diameters wide covers a greater range of latitude near the Jupiter's North Pole than near that planet's equator. Secondly, a belt width would give no information on whether the northern or southern edges of the NEB were changing. For these two reasons, latitudes of the northern and southern edges were measured.

Jupiter has an oblate spheroid shape which is defined by an ellipse that is rotated around Jupiter's axis. Jupiter's equatorial diameter is 1.0694 times its polar diameter. Because of this, there are two ways of defining latitude: zenocentric and zenographic. Zenocentric latitude is the angle between Jupiter's equatorial plane and a line joining the feature to Jupiter's center. Zenographic latitude is the minimum angle between Jupiter's rotational axis and a plane tangent to the feature (19). See Figure 2.

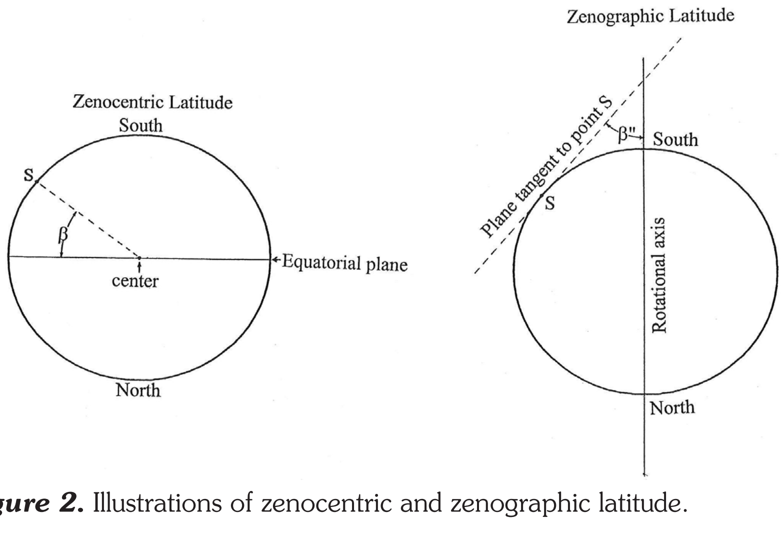

Figure 2. Illustrations of zenocentric and zenographic latitude.

In this paper, the zenographic latitudes are reported. This is what previous studies have used (20). The zenographic latitude (β'') is computed in the same way as in (20):

$$\beta'' = \text{inv Tan}[1.0694 \times \text{Tan}\{SE + \text{inv Sin}[(s - n)/(s + n)]\}] \qquad (1).$$

In this equation, 1.0694 is Jupiter's equatorial diameter (143,082 km) divided by its polar diameter (133,792 km), SE is the latitude of the Sub-Earth point, s is the distance from Jupiter's south limb to the feature and n is the distance from the feature to Jupiter's north limb. Both s and n are measured in the same units. Measurements are made from an image of Jupiter.

An example is worked out using Figure 3. The values of s and n are measured for a feature at point R in the drawing; let's say that s and n equal 30 mm and 27 mm respectively. The value of SE on October 10, 2011 is +3.88° (21). The value of SE is in the Astronomical Almanac and it can also be computed from the JPL Ephemeris Generator on the website http://www.alpo-astronomy.org/. The latitude is computed as:

$$\beta'' = \text{inv Tan}[1.0694 \times \text{Tan}\{+3.88° + \text{inv Sin}[(30\text{ mm} - 27\text{ mm})/(30\text{ mm} + 27\text{ mm})]\}]$$

$$\beta'' = 7.37° \text{ or } 7.4°$$

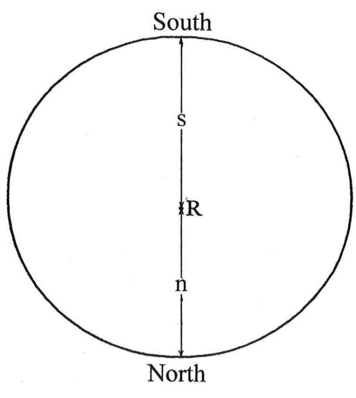

Figure 3. Measurement of the latitude of a feature at point R. It is assumed that this drawing was made on October 10, 2011.

Jupiter's images listed on the website http://alpo-asahikawa-med.ac.jp/Latest/Jupiter.htm were used in this analysis. The analysis was made from images made between 1995 and 2011. In some cases images sent to the writer were also used in the measurements. The people who submitted images are listed in previously published apparition reports (2-14).

Latitude measurements of both the northern and southern boundaries of the NEB were made with the technique just described and equation 1. Since the width can change with longitude, measurements were usually made each month at six system II longitudes 0° – 60°, 60° – 120°, 120° – 180°, 180° – 240°, 240° – 300° and 300° – 360°. Monthly averages were then computed.

RESULTS

Average values of the zenographic latitude of the southern (NEBs) and northern edges (NEBn) of the NEB are plotted in Figure 4; Figure 5 shows the width of this belt. The width is shown in both degrees of latitude and kilometers. The width is computed as the difference in latitude between the southern and northern edges. Typical uncertainties are 0.5 degrees of latitude.

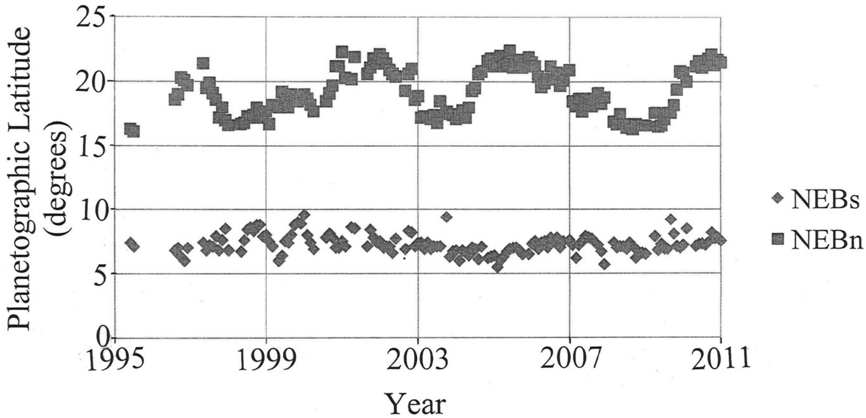

Figure 4. Zenographic latitude of the northern (NEBs) and southern (SEBs) boundaries of the NEB.

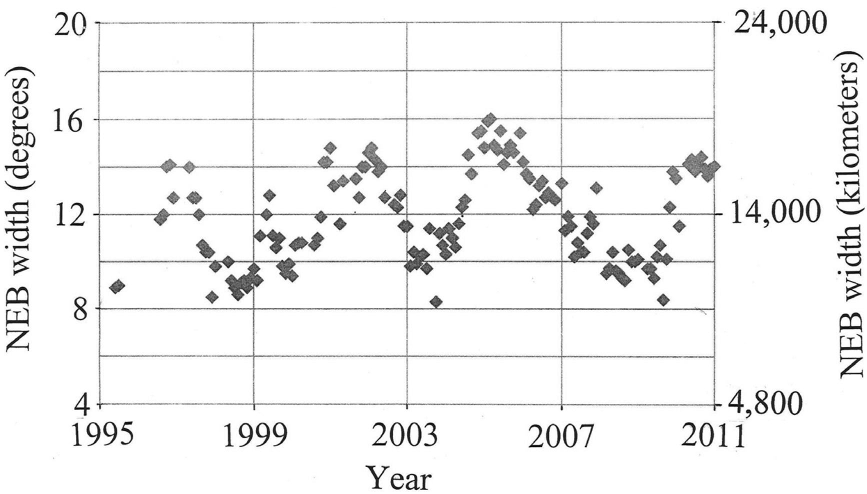

Figure 5. Width of the NEB between 1995 and 2011.

Most of the change in NEB width was due to the changing northern boundary. The northern boundary between 1995 and 2011 oscillated with an average period of 4.5 years. The latitude ranged from 17° N to 22° N. The latitude of the southern border also changed but not by much. Its latitude ranged from 7.0° (late 1999) and 6.5° (late 2004). Based on Figure 4, it appears that the southern border of the NEB reached maximum northerly latitudes in the years 2000 and 2010. The period of oscillation for the southern boundary may be about 10 years.

In the Introduction section, the drift rate was defined and in this section, the way that it is computed is summarized. The first step in computing a drift rate is to measure the longitude of the center of the feature. Longitudes are measured from images two to four times per week. For each measurement, the date is recorded. Once a sufficient number of points is collected the longitudes are fitted to a linear equation with respect to the date using a least squares routine. Consider the following data where λII is the system II longitude: (λII = 102°, May 1.1; λII = 103°, May 5.3; λII = 106°, May 10.1; λII = 106°, May 11.4; λII = 108°, May 18.1; λII = 108°, May 19.1; λII = 109°, May 21.4; λII = 110°, May 24.1; λII = 111°, May 28.1; and λII = 112°, May 31.6). The linear least squares solution is λII = 101.9° + 0.329° × D where D is the number of days after April 30.0. The slope is 0.329°/day and, hence, the drift rate is 9.87°/30 days.

Table I lists the average NEB width along with the number of barges and the average barge drift rate. Values are listed for recent apparitions. A Jupiter apparition is the time when Jupiter is at conjunction with the Sun to when it is again at that point. This lasts about 13 months but varies a little depending on where Jupiter is in its orbit. Three barges were observed during the 1995 apparition. The drift rates for these three were +0.6, -3.7 and -1.1 degrees/30 days. The average of these values is -1.4 degrees/30 days. This value is listed in the fourth column and in the row for the 1995 apparition.

Table I. Average NEB width, the number of NEB barges and average barge drift rate for recent Jupiter apparitions.

Apparition	NEB width (degrees of latitude)	Number of barges	Average barge drift rate (degrees/ 30 days)
1995	9.0	3	-1.4
1996	12.9	0	---
1997	11.2	6	-3.2
1998-1999	9.4	6	-0.4
1999-2000	10.7	1	3.4
2000-2001	12.8	9	-0.3
2001-2002	13.8	13	-2.5
2002-2003	11.0	13	-3.2
2003-2004	11.5	2	-3.0
2004-2005	15.1	12	-3.5
2005-2006	13.2	6	0.4
2006-2007	11.5	0	---
2008	9.8	16	-4.2
2009-2010	10.8	6	1.7
2010-2011	13.5	17	-5

DISCUSSION

Figures 4 and 5 are consistent with the NEB expansion taking place over a few months. This is similar to the length of time for the disappearance of Jupiter's North Temperate Belt in 2002 – 2003 (8) and Jupiter's South Equatorial Belt in late 2009 and early 2010 (2).

The NEB width did not change much during 1955-1985 but it did change between 1896 and 1953. It reached a maximum width 13 times during this time (16). The average interval between successive maxima was 4.8 years with a standard deviation of 1.8 years. This is close to the corresponding values between 1995 and 2011. It is concluded that in years when the NEB's width changes that the behavior is nearly cyclic with an average period of four to five years.

The next question is: How does the changing NEB width affect other features on Jupiter? One feature that may be affected is the NEB barge. This is because it lies either near or inside of the NEB. Accordingly, the number and average drift rate of NEB barges were determined for different NEB widths.

A linear equation and correlation coefficient for the number of barges (k) versus the NEB width was computed. A second linear equation and a correlation coefficient for the average drift rate (DR) versus the NEB width were also computed. The objective was to determine if there is a strong correlation between the variables in each equation. Recall that the correlation coefficient is always between -1.0 and 1.0. Values near zero mean that there is no linear relationship between two variables. A value near 1.0 means that there is a strong linear relationship and a value near -1.0 means a strong negative linear relationship between two variables (22). The results are shown in equations 2 and 3. The correlation coefficient, r, is given in parentheses.

$$\text{NEB width} = 11.1 + 0.09k \quad (r = 0.29) \tag{2}$$

$$\text{NEB width} = 11.4 - 0.19DR \quad (r = -0.26) \tag{3}$$

In both cases, the correlation coefficients are low. Therefore it is concluded that the belt width has little impact on the number of NEB barges or their average drift rate.

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