Development of Ozone Concentration Measurement Methods Based on International Space Station Color Change Observations

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A. Activities

1. Introductions

The International Space Station, the ISS for short, can be seen with the naked eye during the few minutes before dawn or after dusk, under some conditions. During that time, we are able to observe the changes in its color as it emerges into/disappears from view. When it disappears from view, the hue changes from white to red as it darkens. According to *Takada* et al. (2016, *Iiyama* Senior High School), *Matsui* (2017), and *Nakamura* et al. (2018), It is indicated from photographic analysis that the color turns blue in between the change from white to red, which can be explained by “the ISS reflecting light that has passed through the ozone layer, which absorbs red light.” This is based on Button, C. et al. (2013) indicating that there is an area in the ozone layer, called the *Chappuis* Band, where red light is absorbed. *Ishimura* et al. (2019, *Iiyama* Senior High School) has researched under the hypothesis which says that “If the amount of ozone the light passes through is greater, then the blue hue of the ISS as it emerges into/disappears from view will be darker.” We have continued to perform research on this topic. If we succeed, then we will be able to observe the ozone layer, whose depletion is an environmental problem, only by using equipment accessible to senior high school students.

2. The Ozone Layer

The ozone layer is a region of the stratosphere, which is at an altitude of 10~50km, where there is a large amount of ozone. Red light is absorbed when sunlight passes through the ozone layer, enabling blue light to be observed. According to *Matsui* (2017), the change in color of the ISS from white, to blue, and then red is visible as it darkens. It is noted that changes in color can be observed, the red hue due to the troposphere absorbing the blue side of the spectrum, and the blue hue due to the ozone layer absorbing the red side of the spectrum (Fig. 1). The Japan Meteorological Agency has released a global distribution map indicating the monthly mean ozone amount (Fig. 2,3).

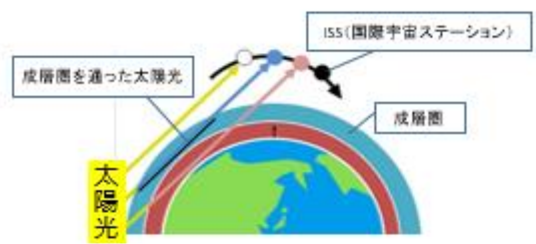


Fig. 1 Diagram of Sunlight Passing Through Ozone Layer

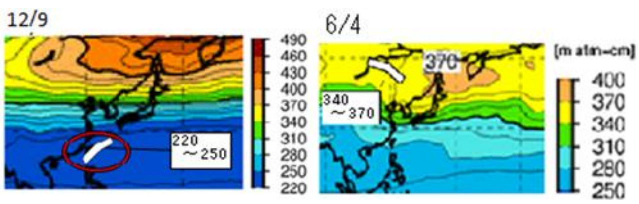


Fig. 2,3 Concentration of Ozone and Area of Stratosphere Where Observed Light Passed Through (White Area)

3. Research

3.1 Test 1 "Is the ISS a darker blue when ozone concentrations are high?"

Comparing the seasonal differences in ozone distribution (Fig. 2,3), the ozone layer tends to be thin on average in Japan and surrounding area in the summer, while being very thick in the north, and very thin in the south from winter to early summer. Moreover, sunlight enters the atmosphere from the north in early summer, and from the south in winter. In other words, the ISS reflects sunlight that has passed through areas of high ozone concentration in the north in early summer, while reflecting light that has passed through areas of low ozone concentration in the south in winter. We think that this method will enable us to see the relation between the changes in the amount of ozone in the atmosphere, and the changes in the color of the ISS.

3.2 Test 2 "Is the ISS a darker blue when it is reflecting sunlight that has passed through the ozone layer?"

If the ozone layer is actually what makes the ISS turn blue as it emerges into/disappears from view, then it should theoretically turn blue in the calculated area where light should pass through the ozone layer.

1. We geometrically calculated the expected areas where the ISS turns blue/red, based on the thickness of the troposphere and the ozone layer.
2. We plotted the expected areas of color change on a map. (Fig. 4,8)(Red: light penetrating troposphere Blue: light penetrating ozone layer)
3. We checked whether the expected areas of color change corresponds with the photographs and the changes on the analytical data graph.

4. Observation

4.1 Method of Photographing

The ISS can be photographed around the timing when it changes hue when the altitude of it emerging/disappearing is high. We performed observations on June 4th, 2019, December 9th, 2019, and January 20th, 2020.

- Used Equipment: Camera "Canon EOS kissX5"
- ISO: 1600, F-Number: 5.6, Consecutive Shooting with a Shutter Speed of Two Seconds

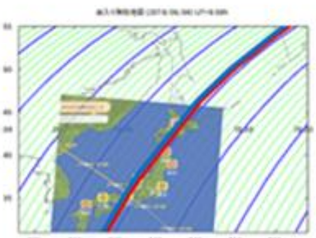
4.2 Method of Analysis

1. We measured the RGB(Red, Green, Blue) values of the ISS hue using the photograph analyzing software "Makalii".
2. We calculated the "B/R value" from the RGB values as an index for the blue hue.

5. Results

Jun. 4th, 2019

Clear, 63° Dissappearing



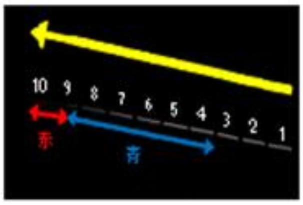
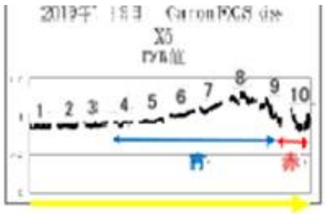


Fig. 4 (Left) Expected Areas of Color Change

Fig. 5 (Right) Photograph of ISS



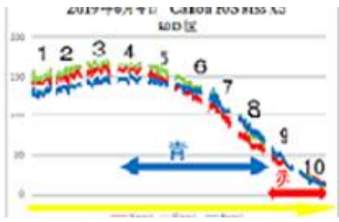


Fig. 6 (Left) B/R Values of Observed Data

Fig. 7 (Right) RGB Values of Observed Data

Dec. 9th, 2019

Sunny, 52°

Dissappearing

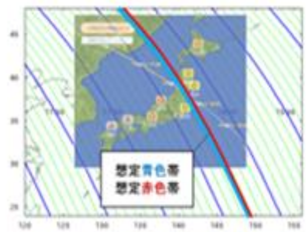
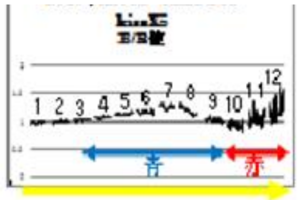


Fig. 8 (Left) Expected Areas of Color Change

Fig. 9 (Right) Photograph of ISS



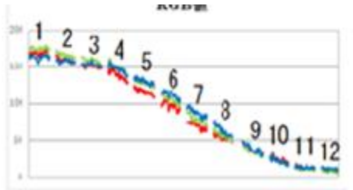


Fig. 10 (Left) B/R Values of Observed Data

Fig. 11 (Right) RGB Values of Observed Data

Arrows of Fig. 5-7, 9-11

↔ *: Areas with Expected Blue Color Change*

↔ *: Areas with Expected Red Color Change*

→ *: Travelling Direction of ISS*

Table 1 Observation Results

Date	6/4	12/9	1/20
B/R Maximum	1.3	1.3	1.3
Ozone Concentration (m atm cm)	340～370	220～250	220～250

- Test 1: No correlation can be seen between ozone concentration and the B/R value in this observation.
- Test 2: The ISS does change color from white, to blue, and then to red. The expected areas roughly correspond with the results, but the peaks were a little out of alignment.

6. Discussion

Judging from the results of Test 1, it cannot be affirmed that "the blue hue of the ISS when emerging/disappearing is darker when ozone concentrations are high". It is difficult to measure the amount of ozone by observing the ISS at this point. We performed the test assuming that the amount of ozone is greater in areas where the concentration is greater, but further examination is needed to verify whether "the concentration is different", or "the thicknesses of the layer are different."

For Test 2, the observed area does not fully correspond with the expected area. However, since we did not have the refraction of sunlight in mind, there is a margin that can be improved.

7. References

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- Web Map https://user.numazu-ct.ac.jp/~tsato/webmap/
- Button, C. et al. "Atmospheric extinction properties above Mauna Kea from the Nearby Supernova Factory spectro-photometric data set" Astron. Astrophys. 549 (2013) A8

B. Problems and Plans for Improvement

We, the *Iiyama* Senior High School Science Club, have been researching the color changes of the ISS, year after year. In fact, this research holds the possibility of being able to monitor "the depletion of the ozone layer", which is a worldwide environmental problem, with technology accessible to senior high school students. This research is also deeply related to the Sustainable Development Goals (SDGs), mentioned in the 2030 Agenda For Sustainable Development adopted by the 2015 United Nations General Assembly. It is relevant to goals: "9. Industry, Innovation, and Infrastructure", and "12. Responsible Consumption and Production".

For that purpose, we will continue researching for solutions to the following tasks:

- The ISS changes its hue from red to blue when it emerges into view in every observation. We will continue to examine the factors of this phenomenon.
- We will examine whether the factor of the amount of ozone is concentration or layer thickness.
- We will examine whether it is relevant or not to calculate with in mind the refraction of sunlight in the atmosphere.
- We will test the effect of light after it is reflected by the ISS until it reaches the camera.

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