Fine-scale visualization of aurora in a wide area using color digital camera images from the International Space Station

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Introduction:

Optical observations of aurora borealis

- ✓ Various ground-based and space-based imagers have been employed
- ✓ Most imagers have not had sufficient spatial and temporal resolution in a wide area

The International Space Station (ISS)

- ✓ Flies at low (~400 km) altitude
- ✓ Takes thousands of upper atmosphere photographs including aurora borealis and aurora austrails with DSLR cameras (ISS images)
- ✓ ISS images have high spatial and temporal resolution in a wide area and they are all uploaded to NASA's website ("Gateway to Astronaut").
- ✓ However, they do not have accurate time and geographical information

Previous study geolocating the ISS images [Riechert et al., 2015]

- ✓ Used star lights to estimate the imaging parameters (e.g., looking direction)
- ✓ Still has a few tens of kilometers errors due to the distance to the stars
- ✓ Difficult to evaluate the time accuracy in a quantitative manner

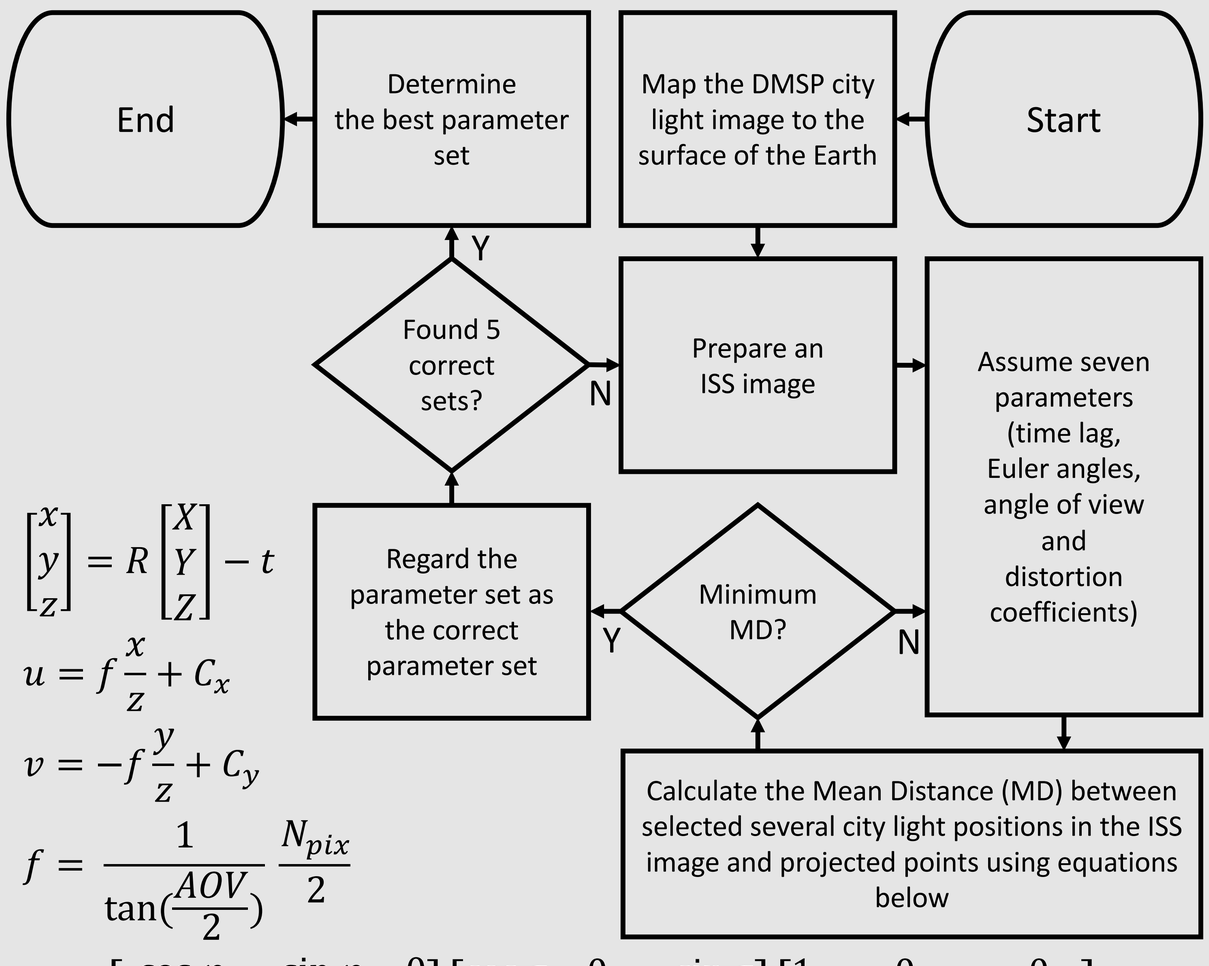
Motivation of this study

- ✓ Establish more accurate mapping method which can be used for detailed analyses of aurora using the other calibration method
- ✓ Evaluate time accuracy quantitatively

	Time res. (s)	Spatial res. (km)	FOV (km x km)
ISS	1.0	0.1	1100 x 900
THEMIS ASI	3.0	2.0	500 x 500
EMCCD ASI	0.01	2.0	500 x 500
IMAGE	120	120	2Re x 2Re
Reimei	0.12	2.0	100 x 100

Proposed Methods:

Calibration method using city light positions [Hozumi et al., 2015]



$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} - t$$

$$u = f\frac{x}{z} + C_x$$

$$v = -f\frac{y}{z} + C_y$$

$$f = \frac{1}{\tan(\frac{AOV}{2})}\frac{N_{pix}}{2}$$

$$R = \begin{bmatrix} \cos\varphi & \sin\varphi & 0 \\ -\sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} \cos\sigma & 0 & -\sin\sigma \\ 0 & 1 & 0 \\ \sin\sigma & 0 & \cos\sigma \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix} R_{ISS}$$

$$u_c = u\,(\,1 + k_1 r^2 + k_2 r^4\,)$$

$$v_c = v\,(\,1 + k_1 r^2 + k_2 r^4\,)$$

Projection of ISS image to the altitude of aurora

- ✓ Calculate the intersection points of the line of sight vector (from ISS to each pixel) and the spheroid whose major and minor axes radius are Re + 100 or 110 km
- ✓ Select the one closer to the ISS as the correct point of aurora

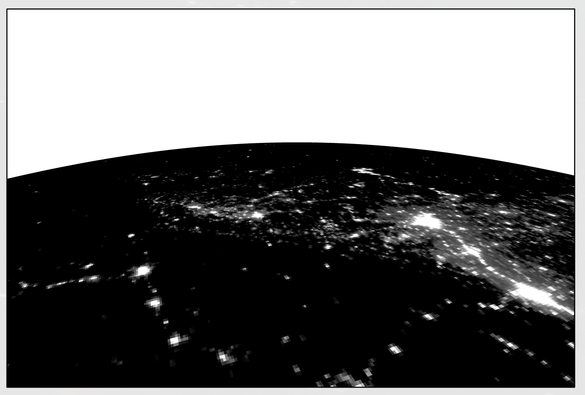
Evaluating the accuracy of the mapping method

- ✓ Compare the spatial structure of discrete aurora and the temporal variation of pulsating aurora (PsA) observed with both EMCCD ASI and ISS images
- ✓ When comparing, the EMCCD ASI data were down-sampled to 3 Hz
- ✓ Calculate the correlation coefficient by shifting the time by 0.1 seconds

Results & Discussion:

Calibration result

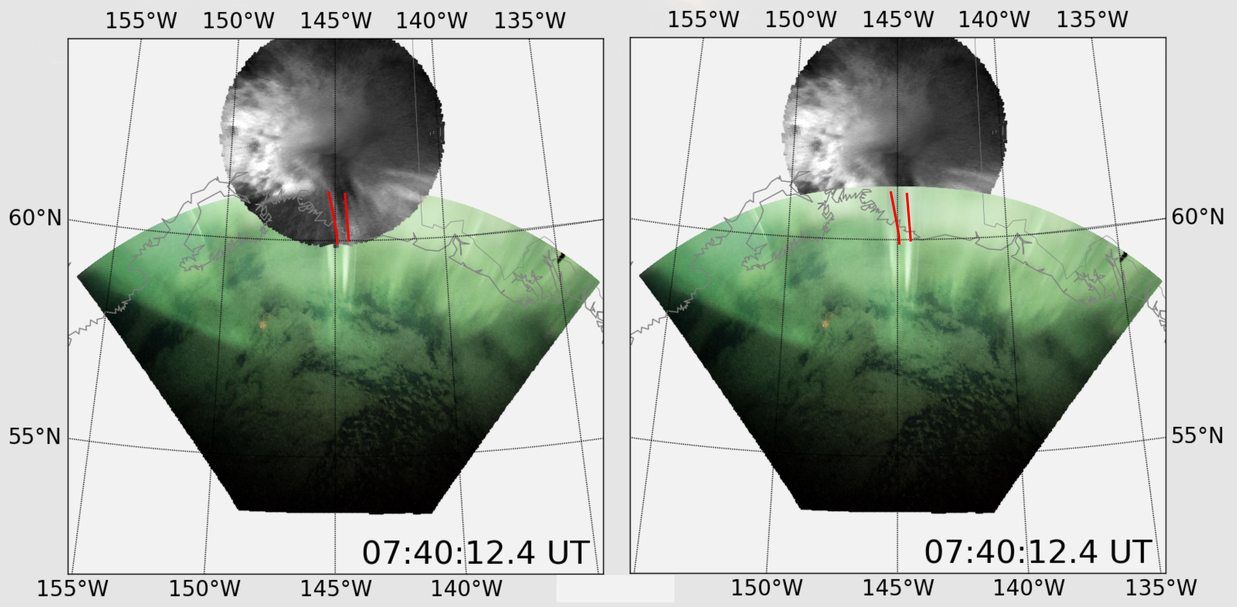
- ✓ The best parameter set gave a minimum mean distance of 2.2 pixels
- ✓ Standard deviation of time lag was 0.3 seconds



Time lag (s)	θ (deg.)	σ (deg.)	φ (deg.)	AOV (deg.)	k_1 (x 10^{-9})	k_2 (x 10^{-16})
-5.6	-86.41	-118.49	-86.17	72.50	-1.4	-1.4

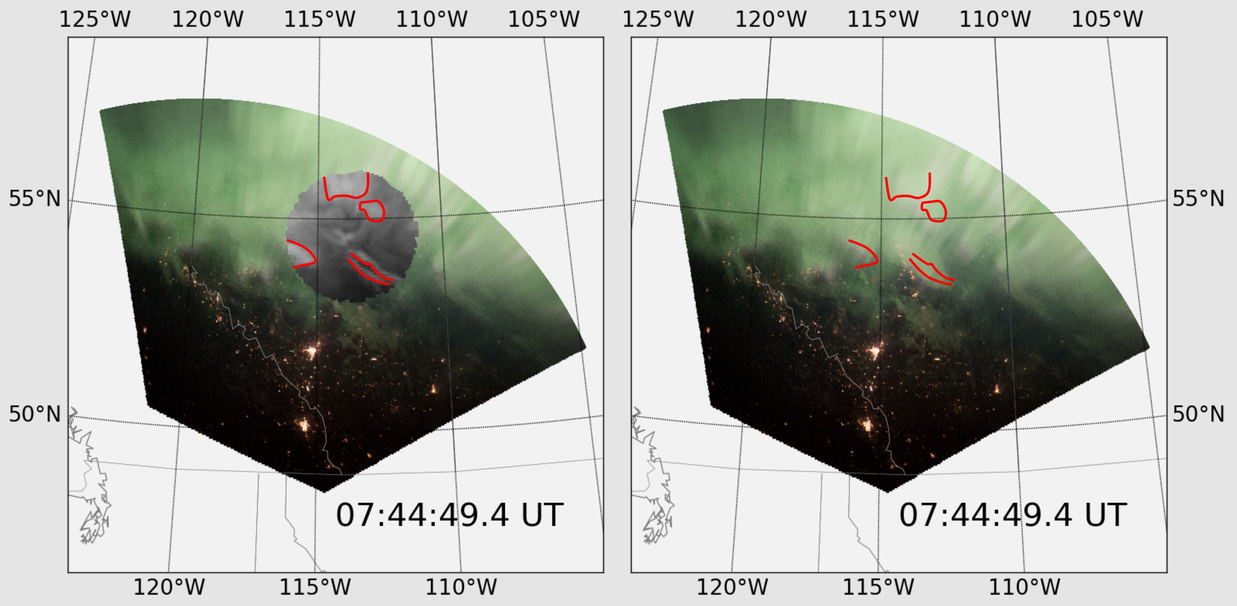
Spatial structure of discrete aurora

- ✓ Compared with the EMCCD ASI data from Gakona, Alaska
- ✓ Confirmed the locations of two arcs agree within an accuracy of 0.5 degrees
- ➢ Spatial accuracy of the mapping is **10 - 20 km**



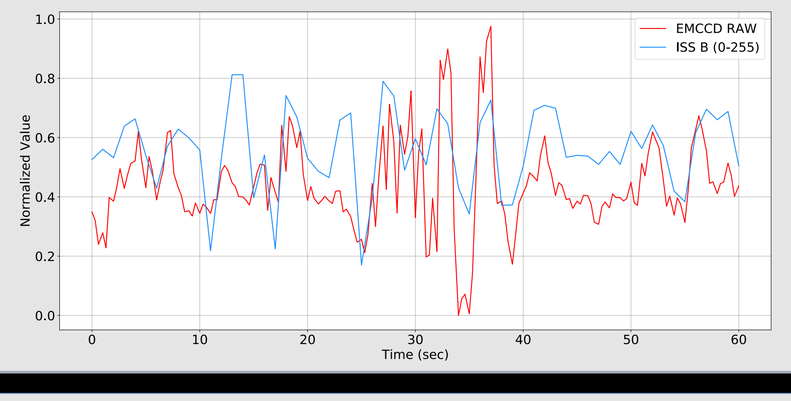
Spatial structure of PsA

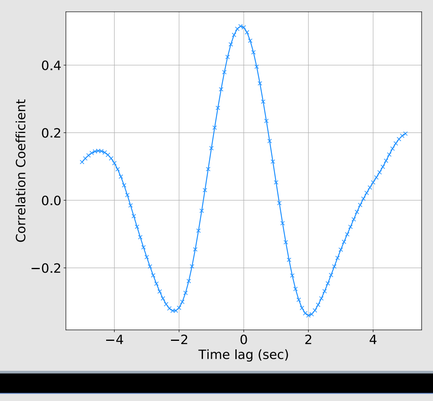
- ✓ Compared with the EMCCD ASI data from Athabasca, Canada
- ✓ Confirmed the spatial structure shows good agreement only in the direction perpendicular to the line of sight of ISS camera



The temporal variation of PsA

- ✓ Compared the temporal variation of PsA from EMCCD ASI at Athabasca
- ✓ Confirmed a peak-to-peak correspondence with less than 1 second offset
- ✓ The correlation coefficient was maximized at a time lag of 0.1 seconds
- ➢ Time accuracy of the mapping is **less than 0.3 seconds**





Conclusions:

- ✓ Spatial accuracy of the proposed mapping method is less than 5 km in the direction perpendicular to the line of sight of ISS camera
- ✓ Time accuracy of the proposed mapping method is less than 0.3 seconds
- ✓ The data sets can be used for studying the temporal variation of PsA

Future works:

- ✓ Derive the MLT dependence of the pulsating period of PsA
- ✓ Examine the relationship between the motion of PsA and the background plasma convection obtained from SuperDARN