Cloud tracking in Venus using Rotation Invariant Phase Only Correlation

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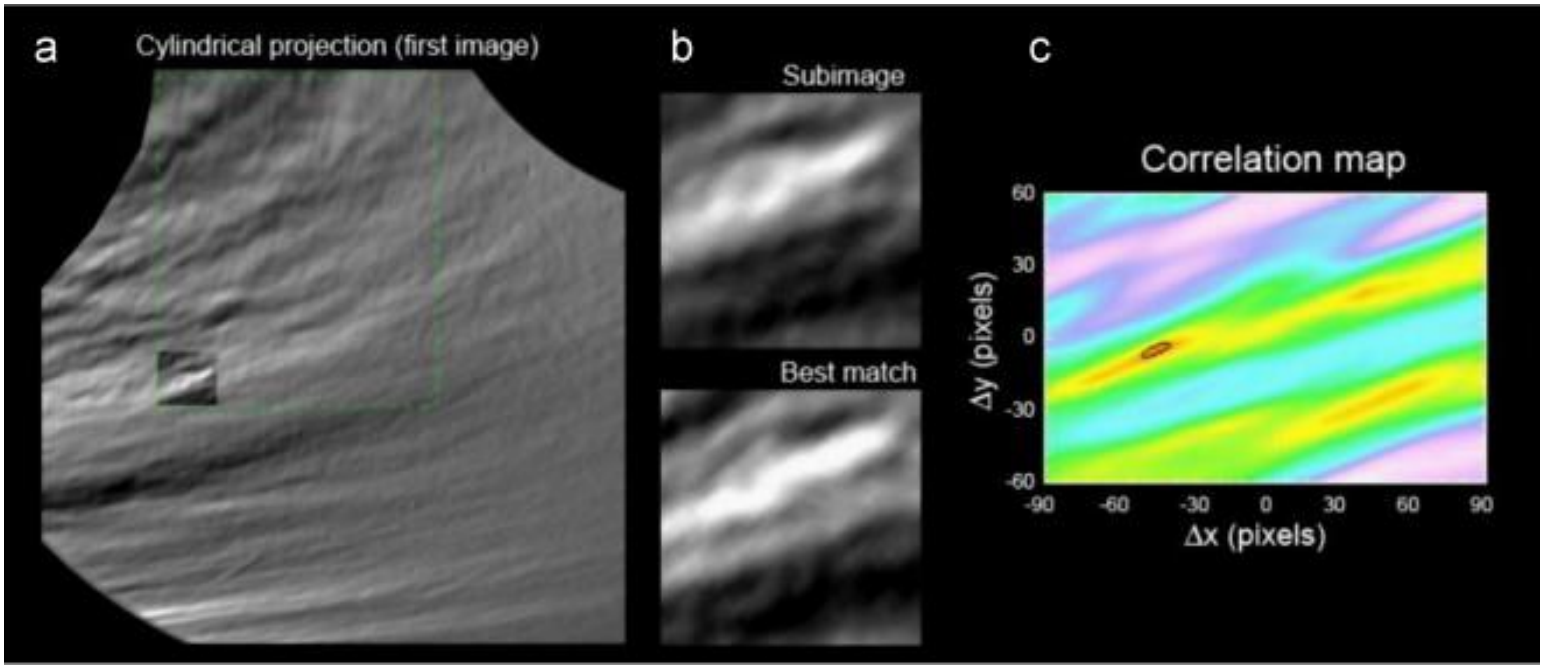
Measurement wind speed in Venus

- A cross correlation method has been mainly used for measured wind speed in Venus.
- We measured wind speed by using phase correlation method.



Hueso et al. 2015

Phase correlation Method

- We can obtain sharper correlation peaks by using phase correlation method than cross correlation method.

$$A(k,l) = \int \alpha(x,y)\, e^{-i(kx+ly)}\, dx\, dy$$

$\alpha(x,y)$: image1
$\beta(x,y)$: image2
$\beta(x,y) = \alpha(x-a, y-b)$

$$B(k,l) = \int \beta(x,y) e^{-i(kx+ly)}\, dx\, dy = \int \alpha(x',y') e^{-i[k(x'+a)+l(y'+b)]}\, dx'\, dy' = A(k,l) e^{-i(ka+lb)}$$

$y' = y - a$
$x' = x - a$

$A(k,l)$: Spectrum of $\alpha(x,y)$
$B(k,l)$: Spectrum of $\beta(x,y)$

normalized cross spectrum

$$F_{AB}(k,l) = \frac{B(k,l)\, A(k,l)^*}{\left|B(k,l)\right|\left|A(k,l)^*\right|} = e^{-i(ka+lb)}$$

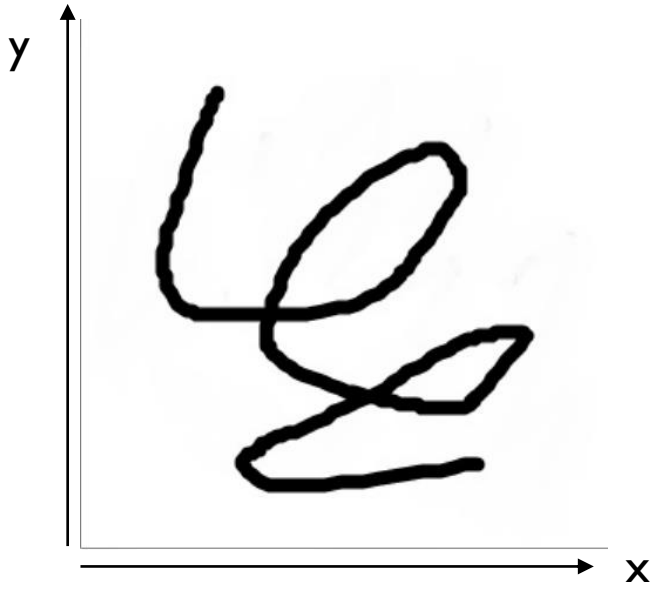
POC function

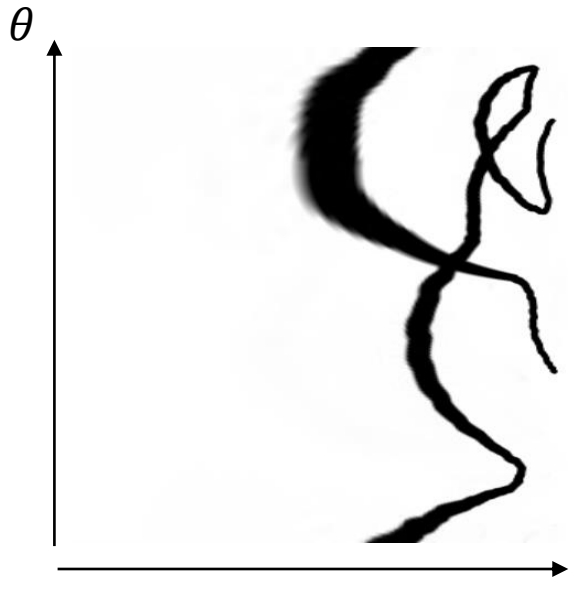
$$Q(x,y) = \int e^{-i(ka+lb)} e^{i(kx+ly)}\, dk\, dl = \delta(x-a, y-b)$$

a:translative offset in x axis
b:translative offset in y axis

Measurement rotation angle

- By using phase correlation method, translative offset of images can be measured but the rotation of image can not be considered.
- To take into account the rotation of the image, we make log-polar transformation images.



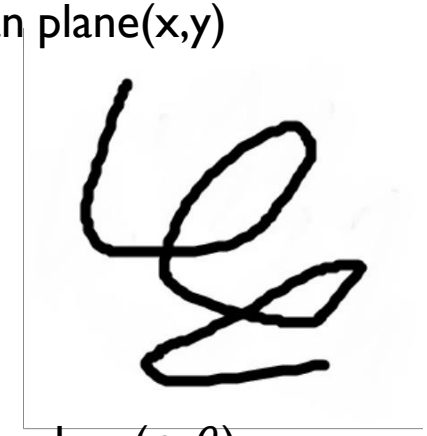


$$\begin{cases} \rho = \log\sqrt{x^2+y^2} \\ \theta = \arctan y/x \end{cases}$$

Measurement rotation angle

- Rotation angle can be measured by the phase-only correlation method because the rotation angle θ becomes the y-axis in the log-polar plane.

cartesian plane(x,y)



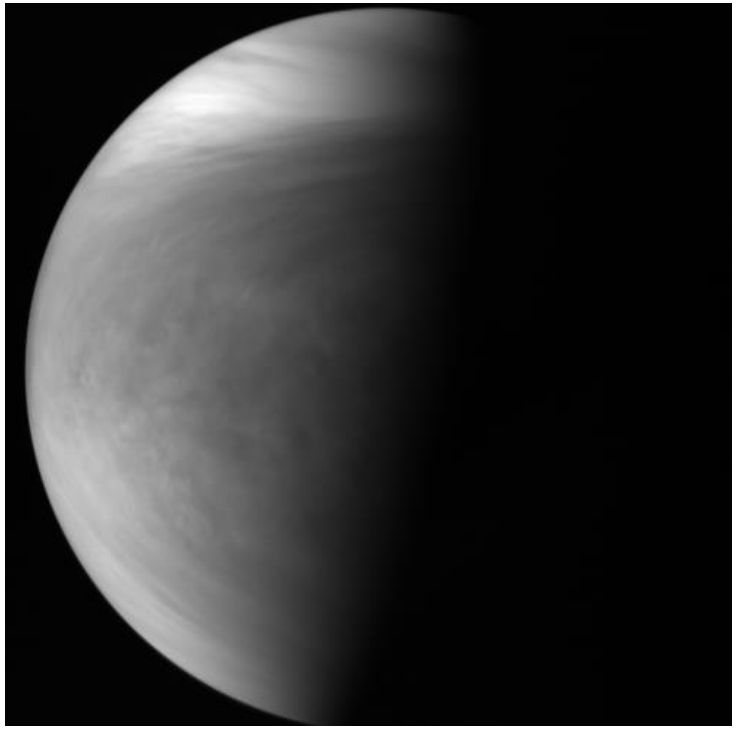
Rotate 90°

log-polar plane(ρ, θ)

Shift θ-axis

Data set

- We used images taken by UVI on Akatsuki.
- We measured cloud motion vectors by cloud tracking using UVI(365nm) images on Akatsuki.



Akatsuki UVI image(365nm)

Method

Translative offset is roughly estimated by visual inspection.

Considering the rotation of images by Venus' super rotation, images are obtained according to the average wind speed obtained by Hueso et al. 2015.

Measured translative offset between two images by using phase correlation method.

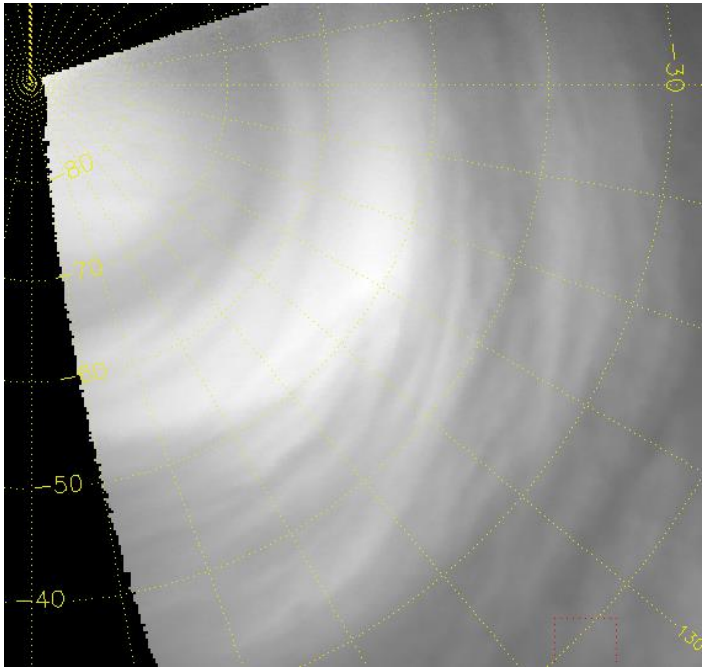
Reselect images according to the measured translation translative offset.

Measured rotation angle of images by log-polar transformation images.

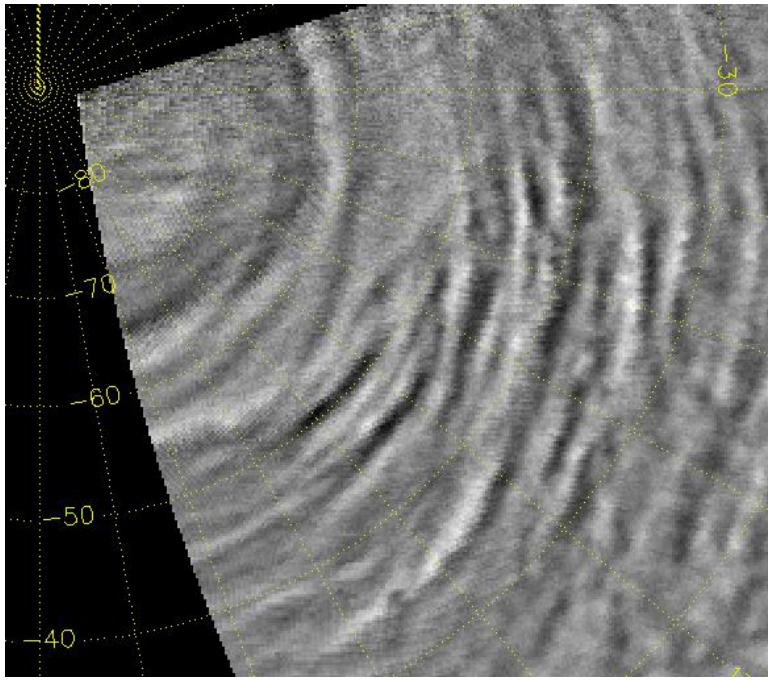
Rotate images according to the measured rotation angle, and measured translative offset by using phase correlation method.

Method：1

Take the difference between the moving average of 16 pix and the original image.(Structure with scales of several hundred kilometers or less are extracted.)



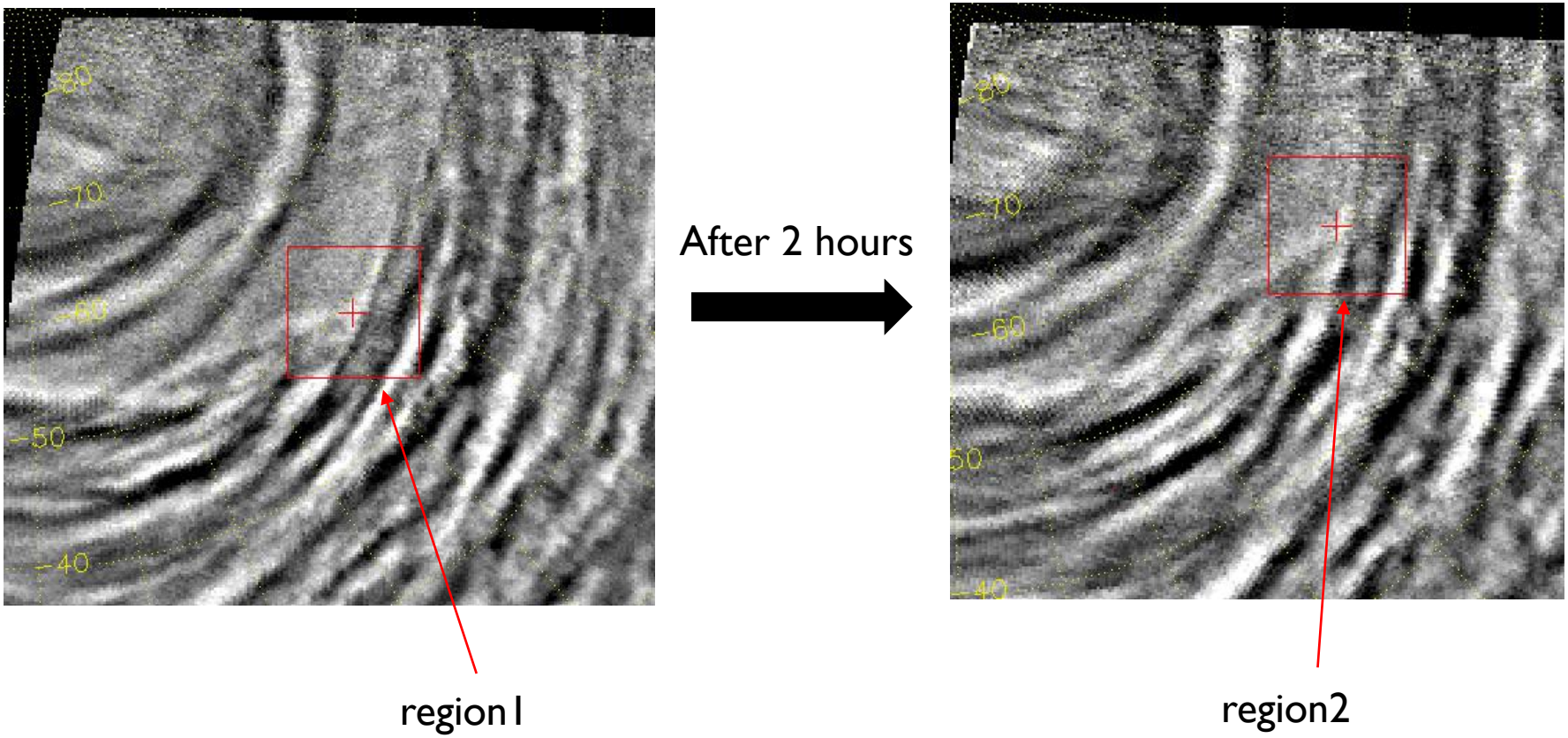
Original image



Applying a high-pass filter for left images

Method：2

Visually select tracking region 1 and 2 from the two UVI images.



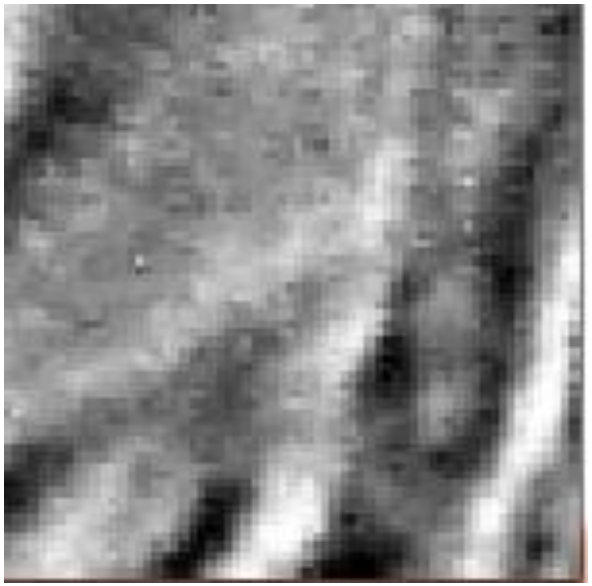
Method：3

・Considering the rotation of images by Venus' super rotation, images are obtained according to the average wind speed obtained by Hueso et al. 2015.

・Measured translative offset between two images by using phase correlation method.

region1

Rotated region1 according to Hueso et al. 2015



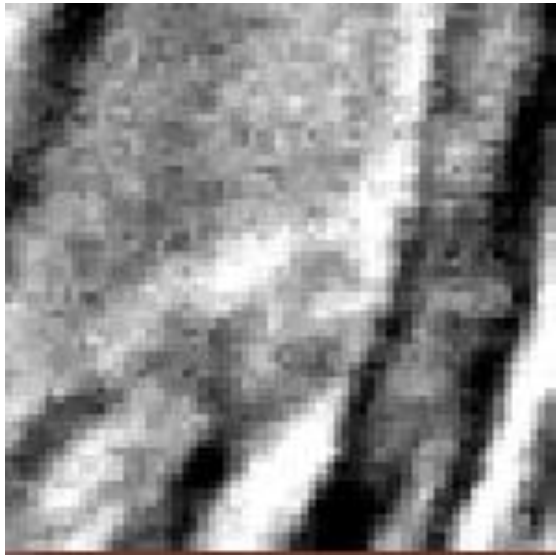
region2

Method：4

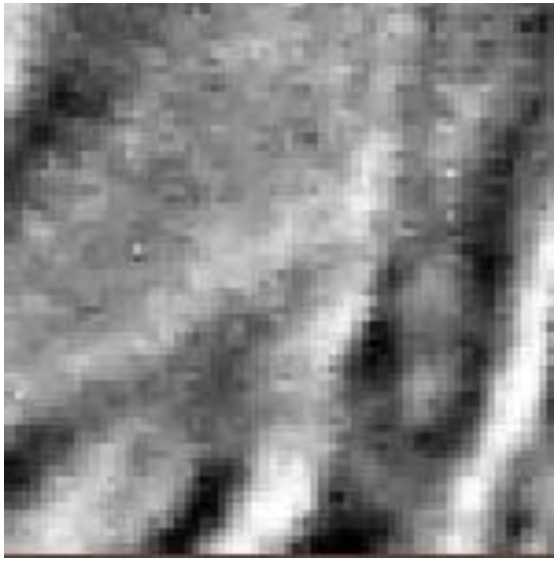
- Reselect tracking regions according to the measured translation translative offset and measured rotation angle of images by log-polar transformation images
- Rotate images according to the measured rotation angle, and measured translative offset by using phase correlation method.

region1

region1 after rotation

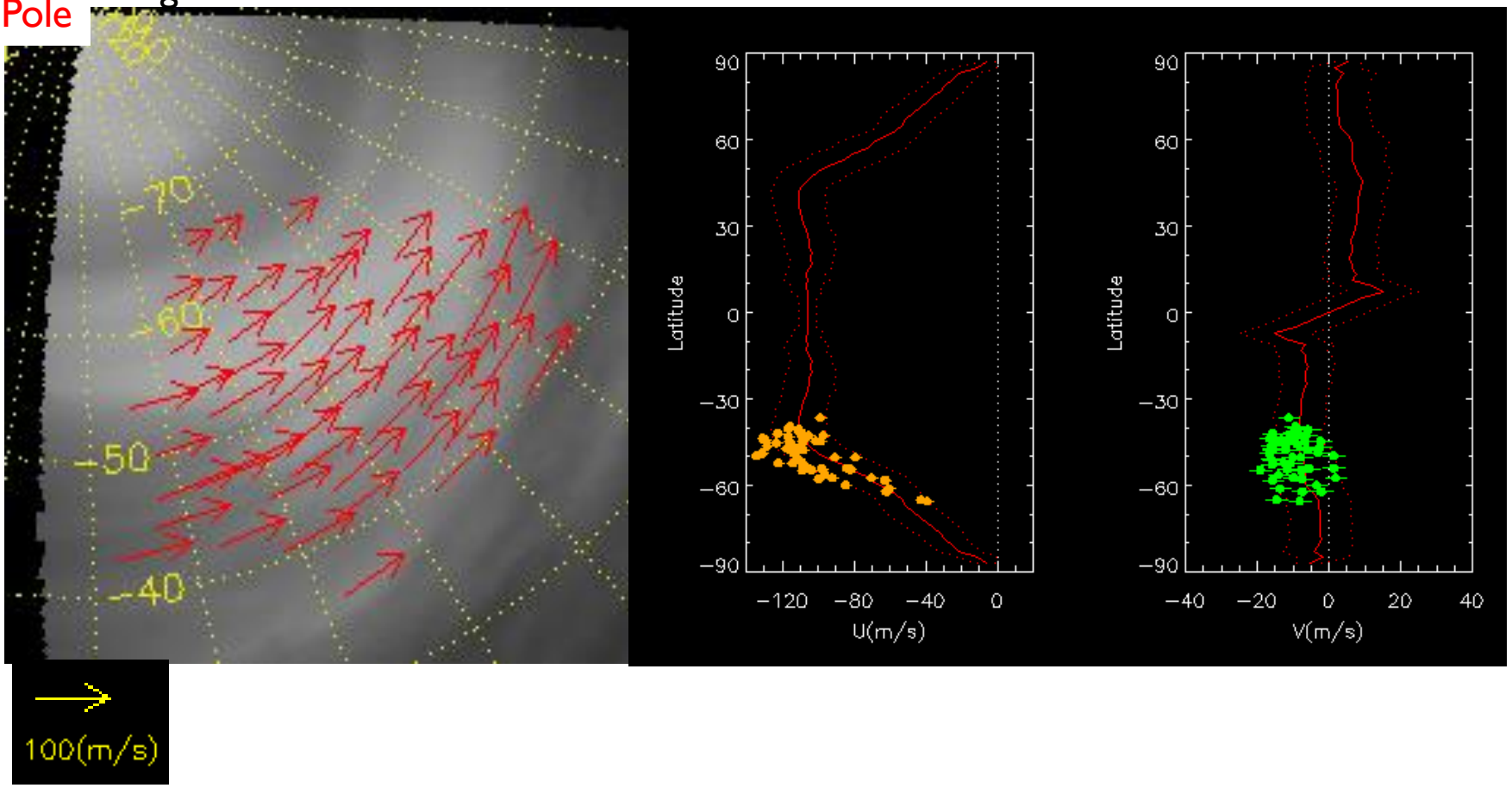


region2



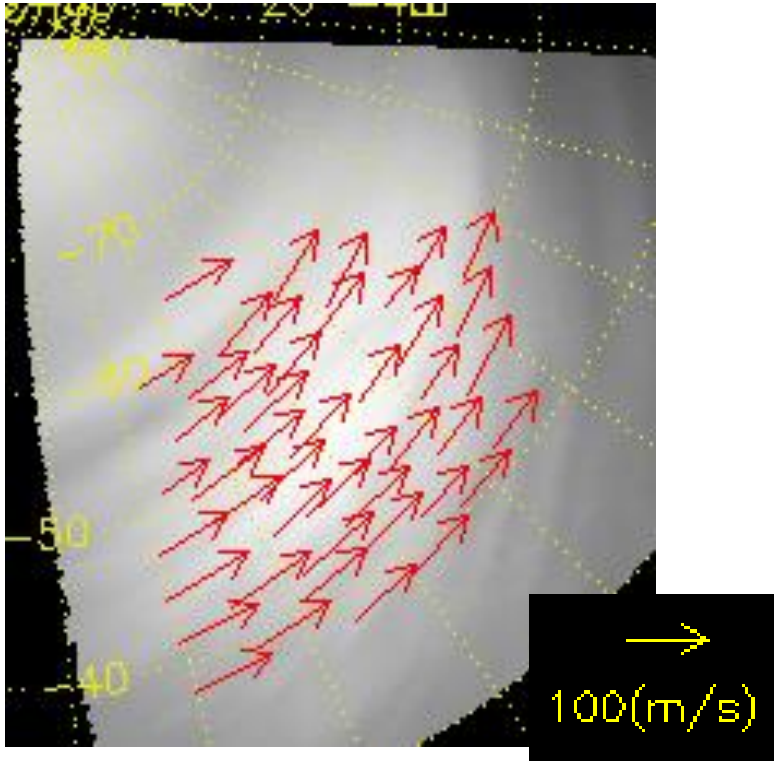
An example of wind speed field(2016-08-03)

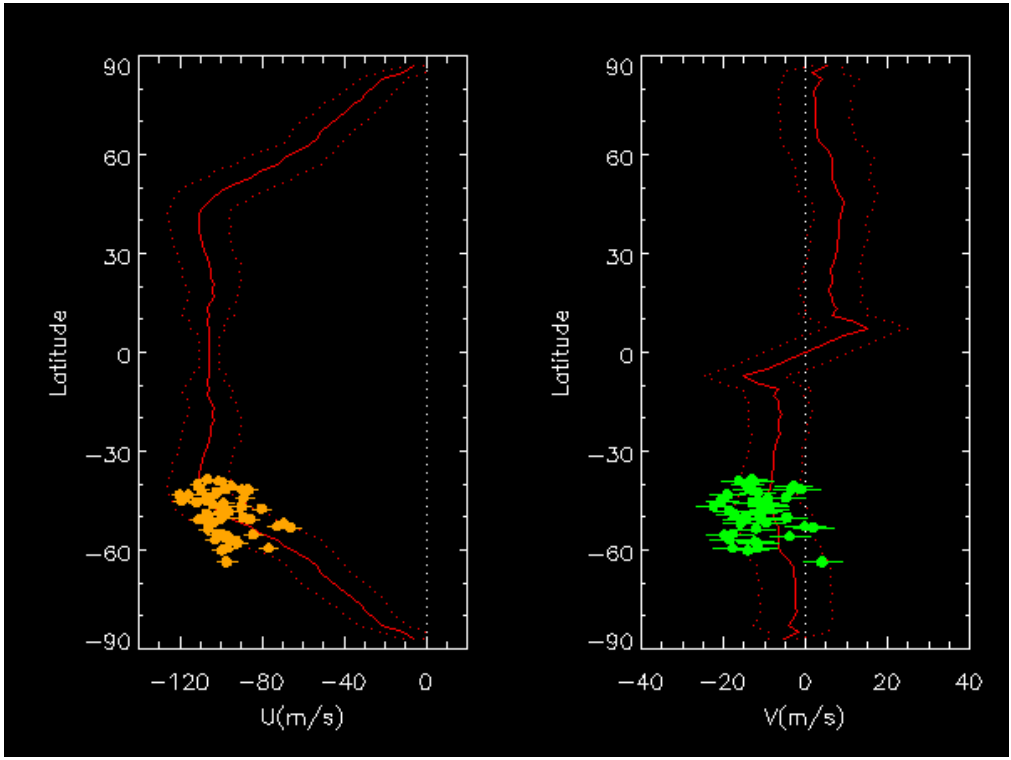
Brightness & cloud motion vectors



An example of wind speed field(2016-08-14)

Pole Brightness & cloud motion vectors





Measured rotation angle (2016-8-14)

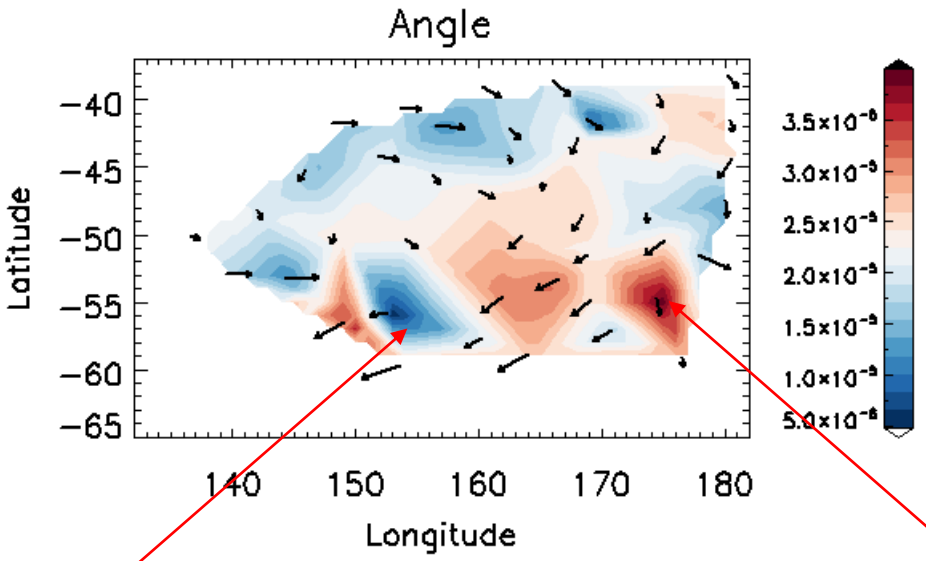


image1

image2

image1

image2

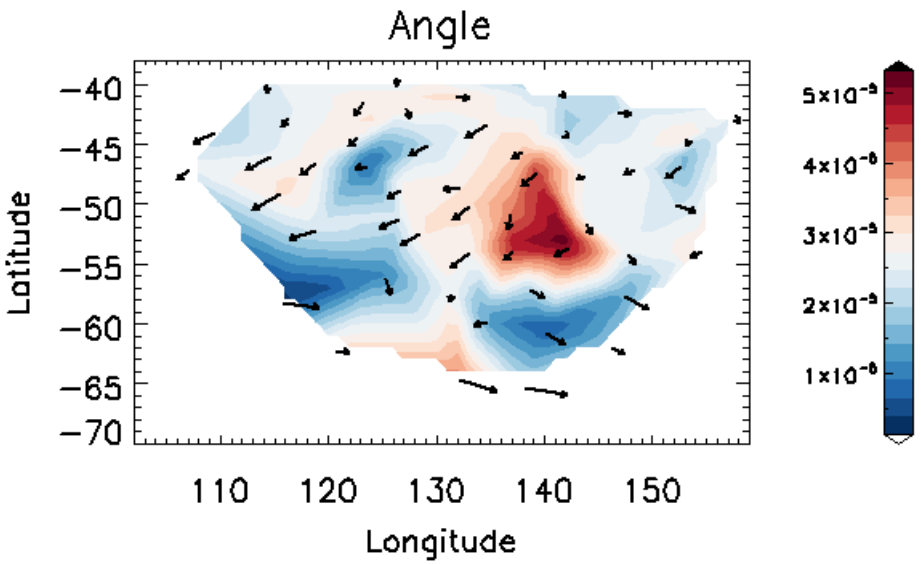
Rotation and rotation angle

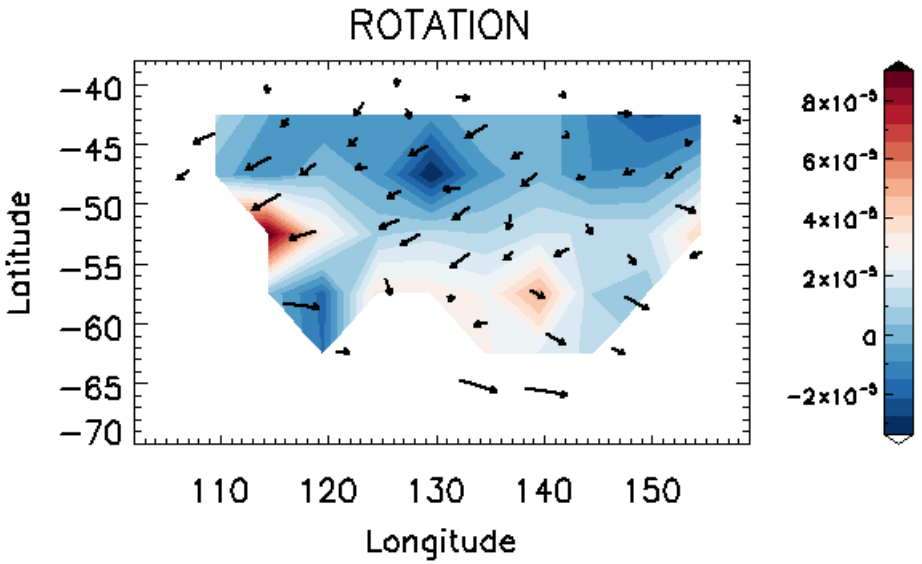
- In this study, cloud tracking is performed by visual inspection, so obtained wind speed vectors are distributed inhomogeneously.
- The rotation of the wind speed field in the spherical coordinate system is obtained by using the averaged wind speed calculated for bins of 5° latitude and longitude.
- We compared the rotation and the rotation angle directly obtained from the image

$$\text{Rotation}: \left. rot\vec{A} \right|_{r=R} = \frac{1}{(R+h)\cos\theta}\left[\frac{\partial(A_\varphi \cos\theta)}{\partial\theta} - \frac{\partial A_\varphi}{\partial\varphi}\right]$$

R: Venus radius[km]
θ: Latitude[rad]
φ: Longitude[rad]
h: 70[km]

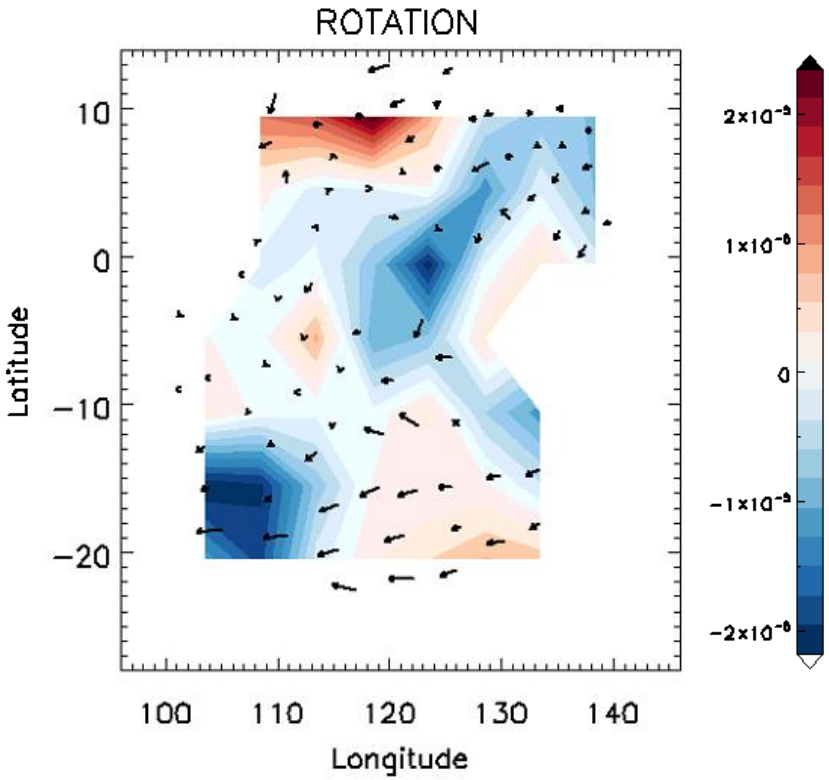
Rotation and rotation angle(2016-8-3)

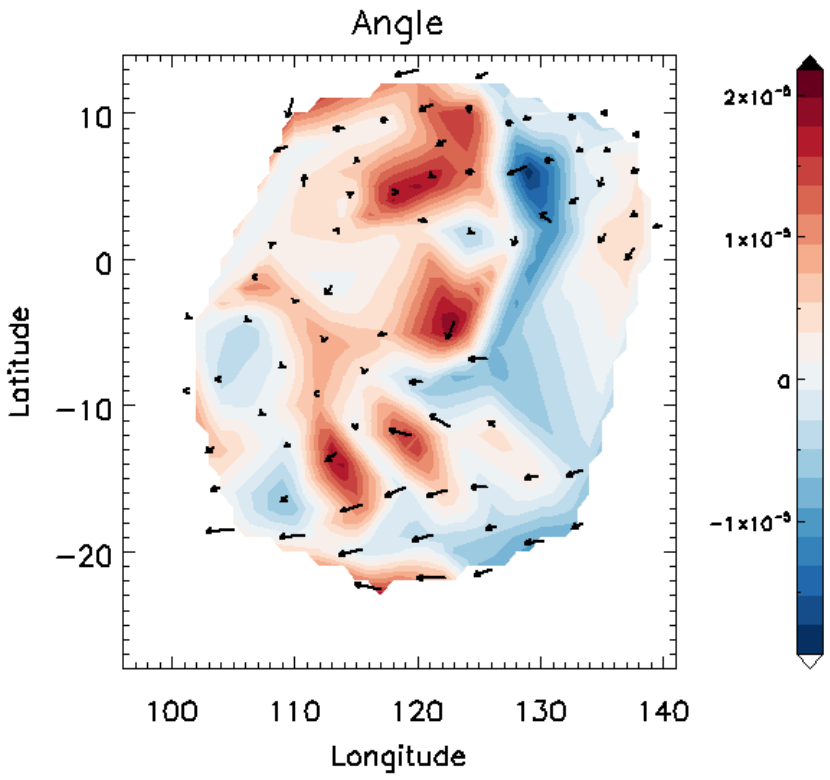




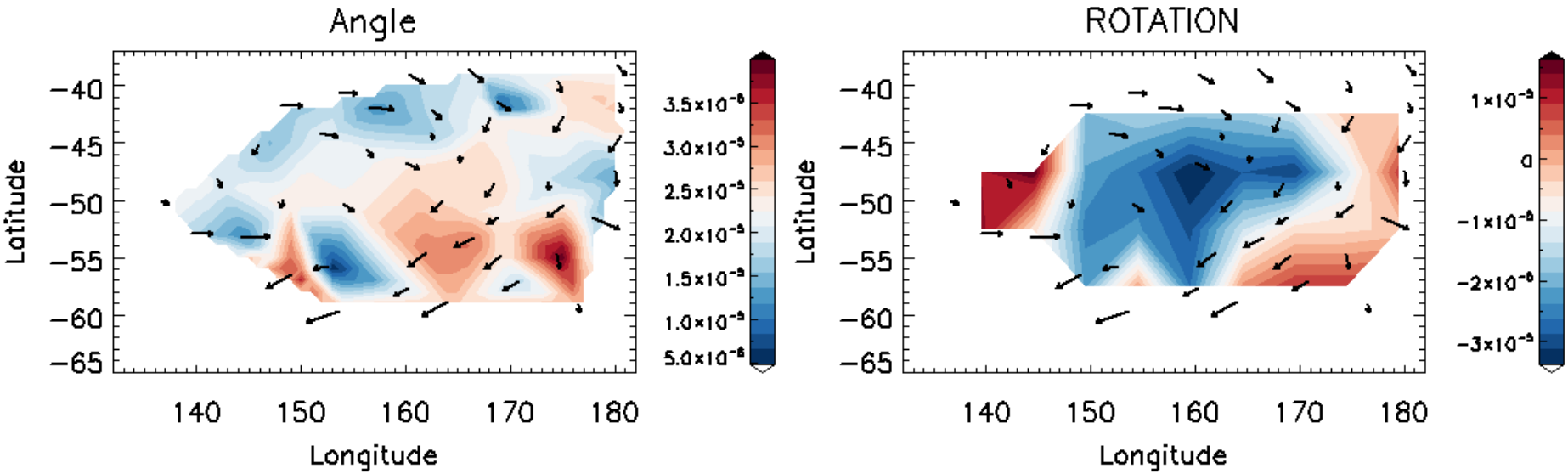
The solid body rotation component that is 150 m / s at the equator is subtracted.

Rotation and rotation angle(2016-8-3)



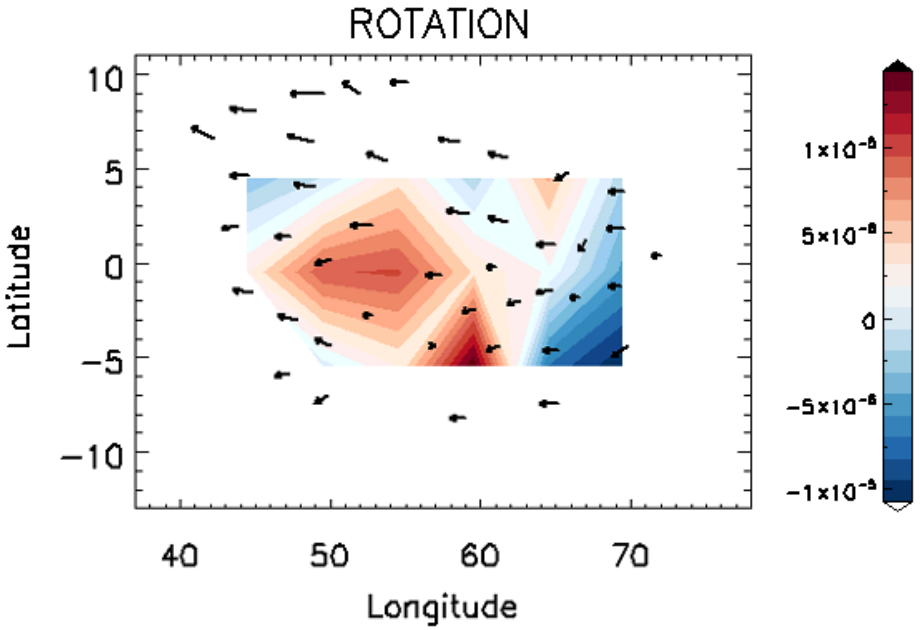


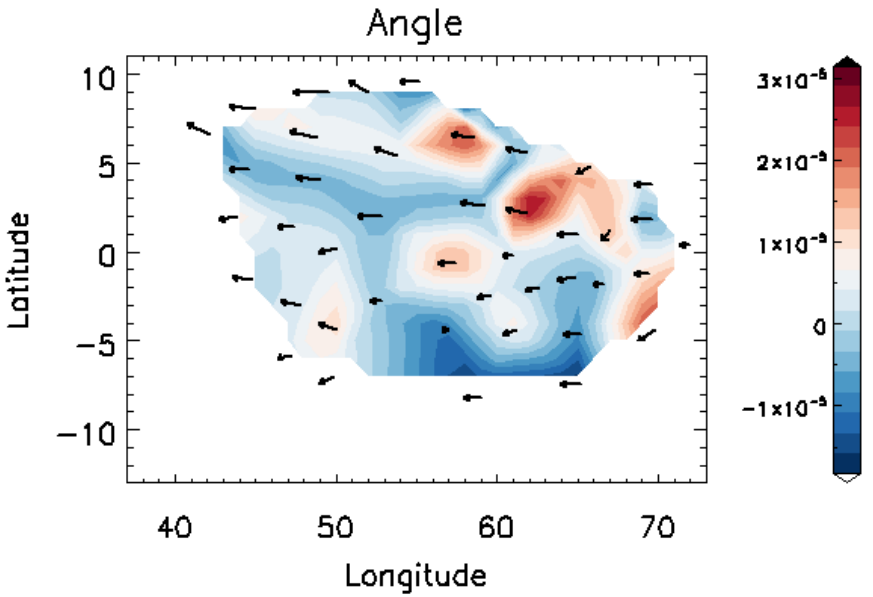
Rotation and rotation angle(2016-8-14)



The solid body rotation component that is 150 m / s at the equator is subtracted.

Rotation and rotation angle(2016-10-7)





Summary

- By using the rotation invariant phase-only correlation method for the ultraviolet image of the inconvenience, we measure wind speed field of high latitude.
- By comparing the rotation and the rotation angle directly obtained from the image, the detailed structure of the rotation angle can be confirmed more than the rotation.
- We can obtain a smaller spatial scale vortex and wave than before by using the obtained rotation angle,