For Brain Storming: UV Cloud tracking

- Method and Results in my study
- Discussion topics
  - Template size dependency
  - Difficulty of cloud tracking in Middle and High latitude regions

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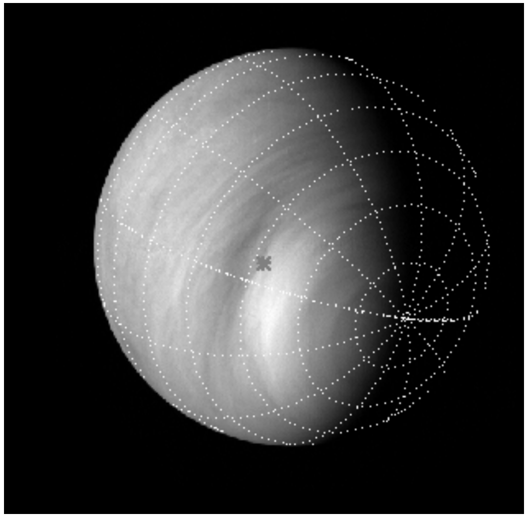
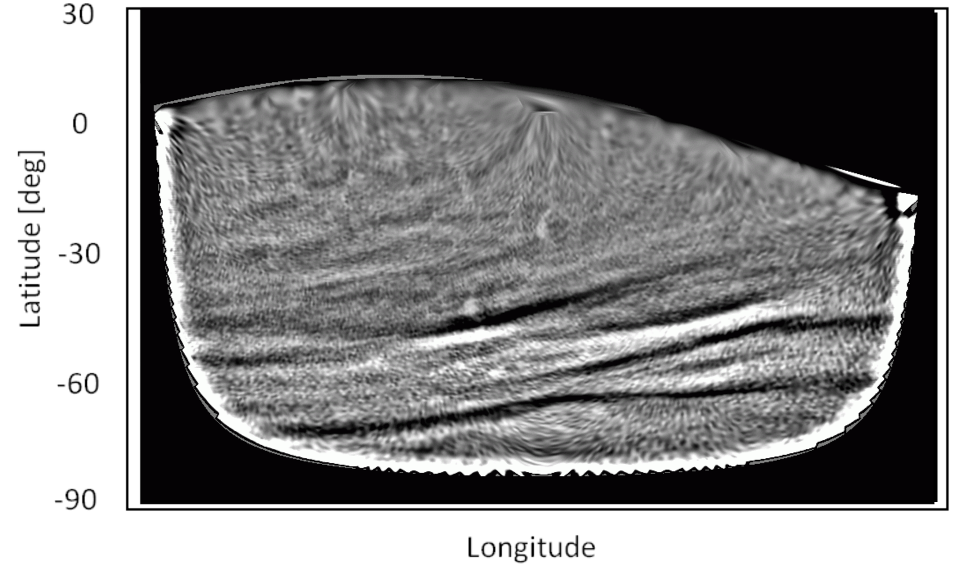
Cloud tracking procedure

Venus Express/VMC



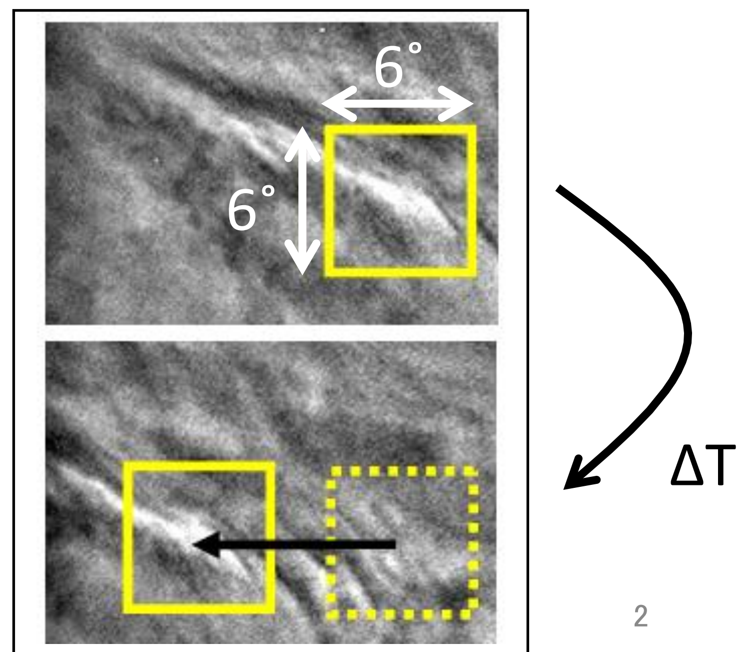


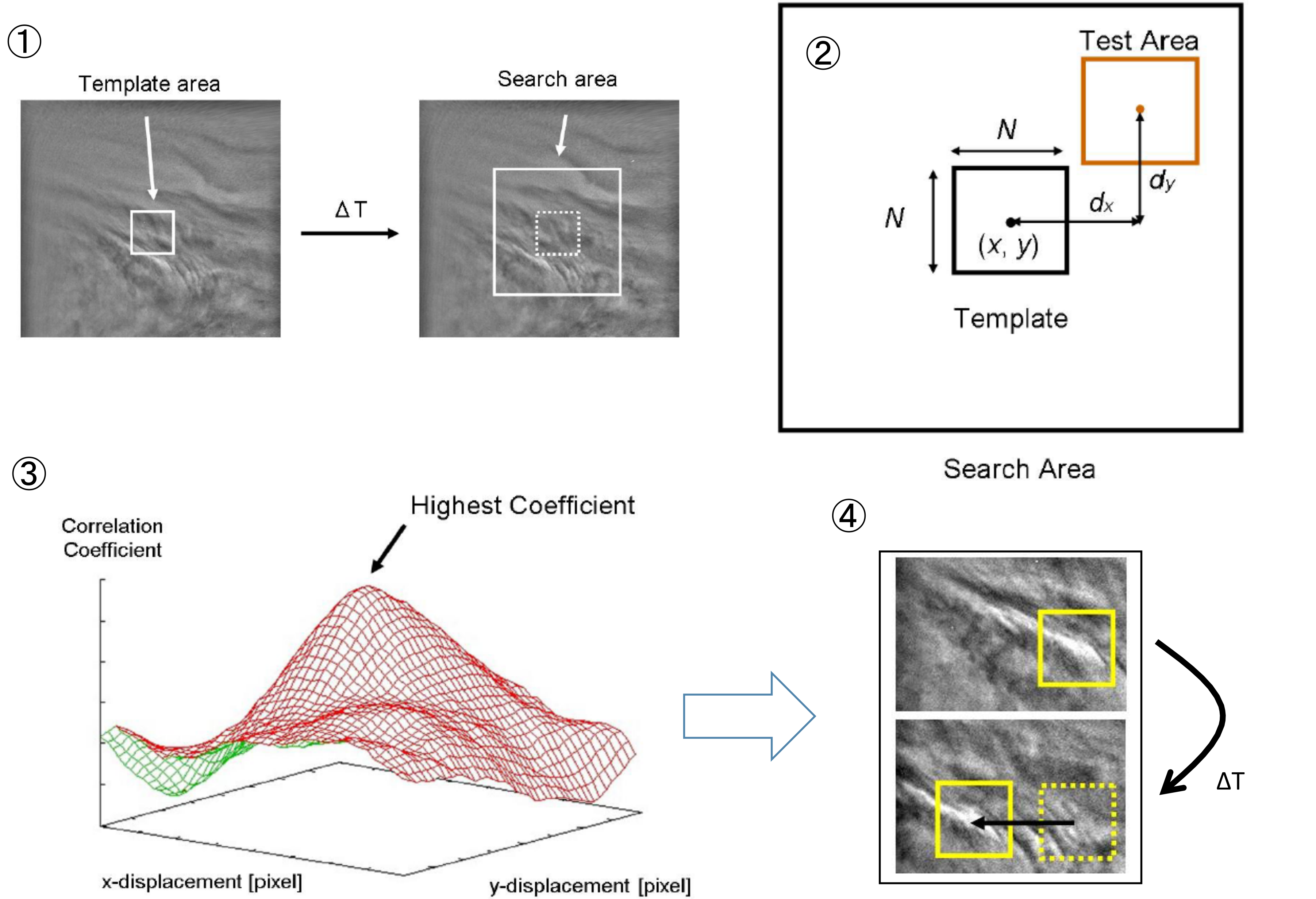
1. Projecting original image onto latitude-longitude coordinate map

2. Tracking cloud features

・Deducing speed from cloud motion with cross correlation between pair images (Digital trackgin).

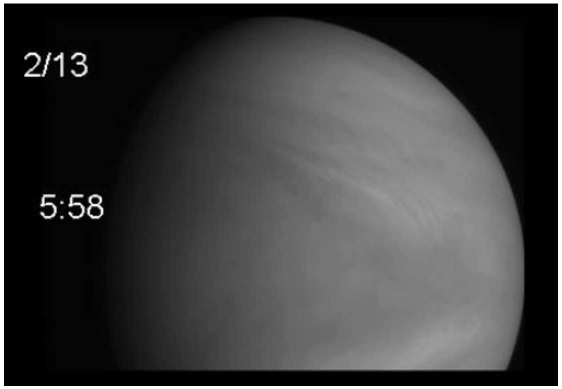
・Template: 6˚x6˚ with 3 ˚ interval



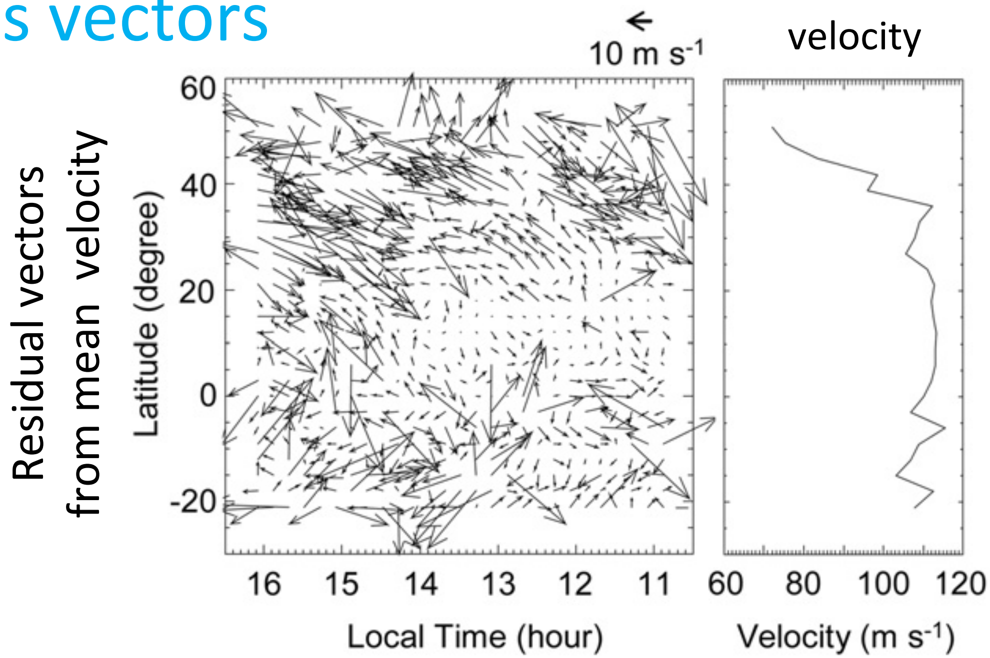

①
Template area
Search area
ΔT
②
Test Area
N
N
dx
dy
(x, y)
Template
Search Area
③
Highest Coefficient
Correlation
Coefficient
x-displacement [pixel]
y-displacement [pixel]
④
ΔT

Examples of Erroneous vectors

Feb. 13. 1990
Galileo/SSI

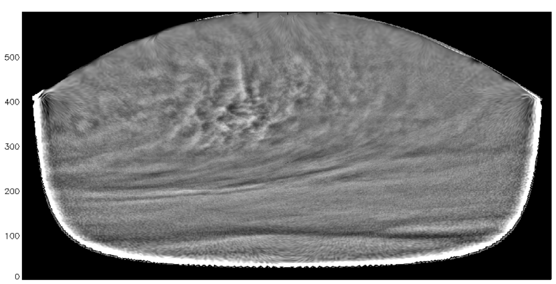


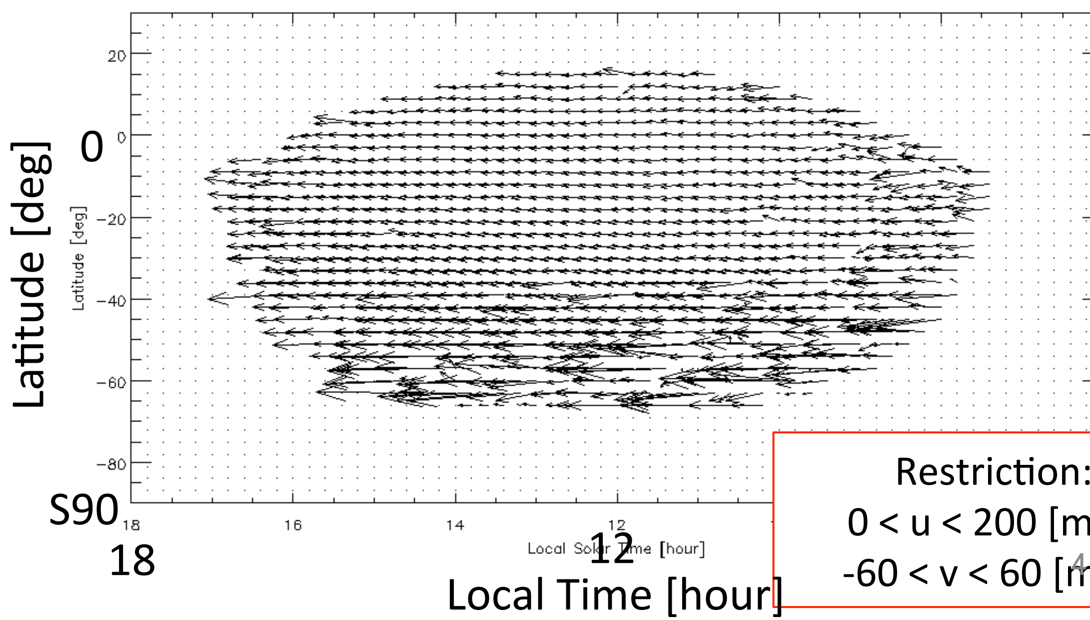
Mean zonal velocity



[Kouyama et al., 2011]

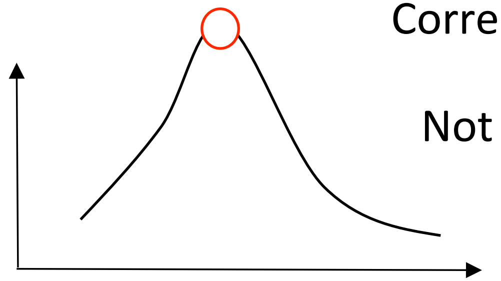
VMC data
(orbit# 0462)





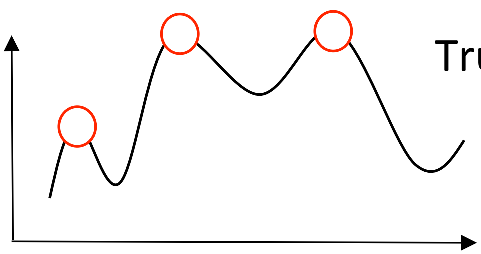
Restriction:
0 < u < 200 [m/s]
-60 < v < 60 [m/s]

Erroneous vectors

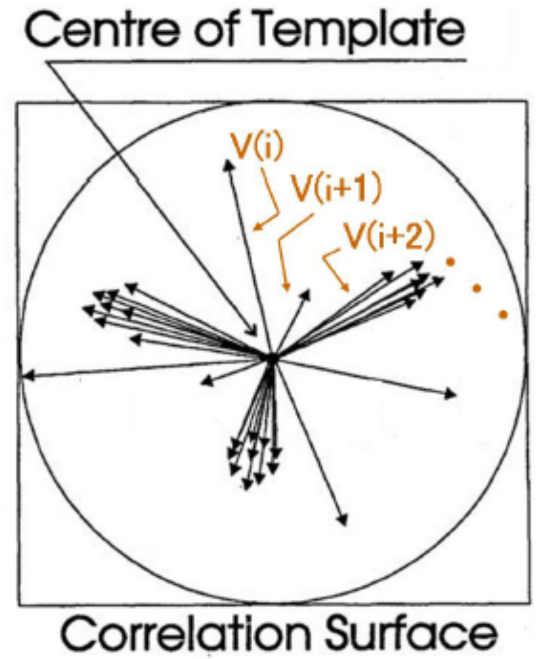


Correlation surface has…

Not – Always Single peak



True – Some times
Multiple peaks



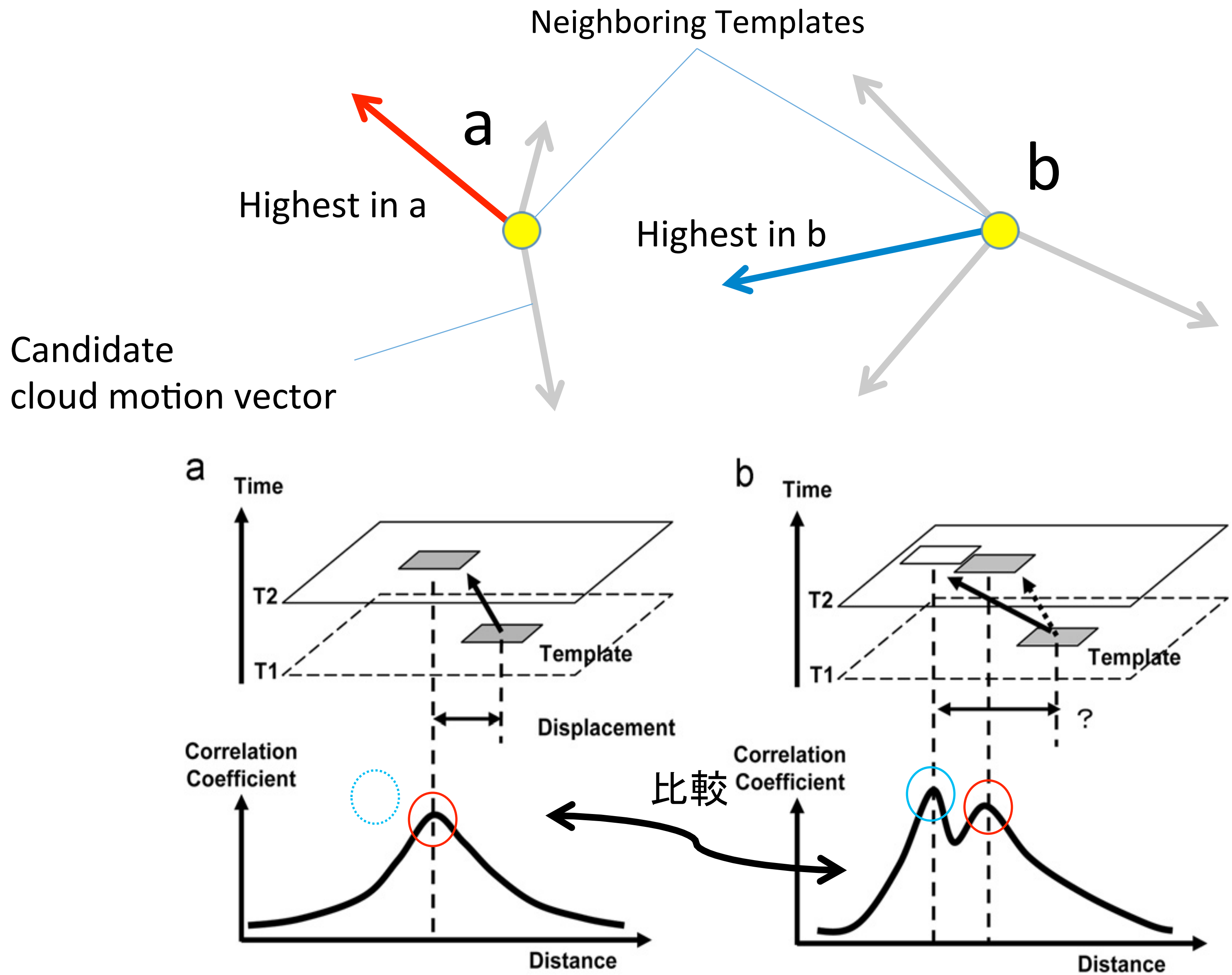
[after Wu, 1995]

◇ Cloud tracking technique using Probabilistic Relaxation for avoiding to select erroneous vectors [Wu, 1995; Evans 2000]

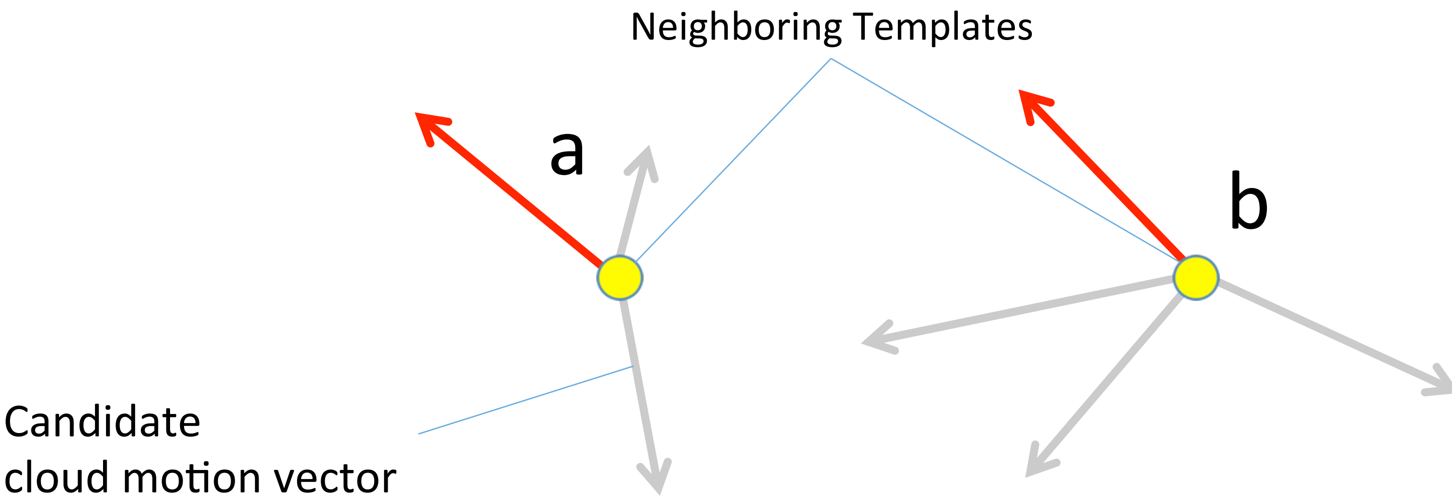
1. Considering not only a vector whose correlation coefficient is the highest, but also many other candidate vectors.
2. Comparing each candidate vector with candidate vectors from nearby templates, then choose a vector as more plausible motion vector whose direction is well reasonable with fluid continuity.

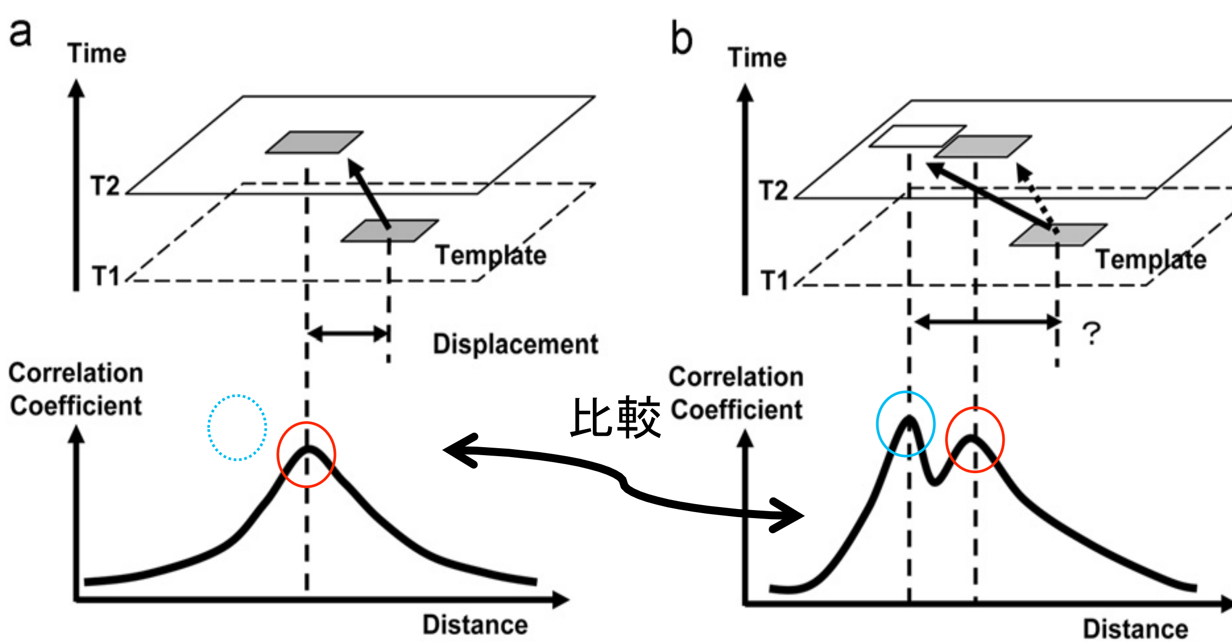
Avoiding to select erroneous vectors

[Wu, 1995; Evans, 2000; Fanning]

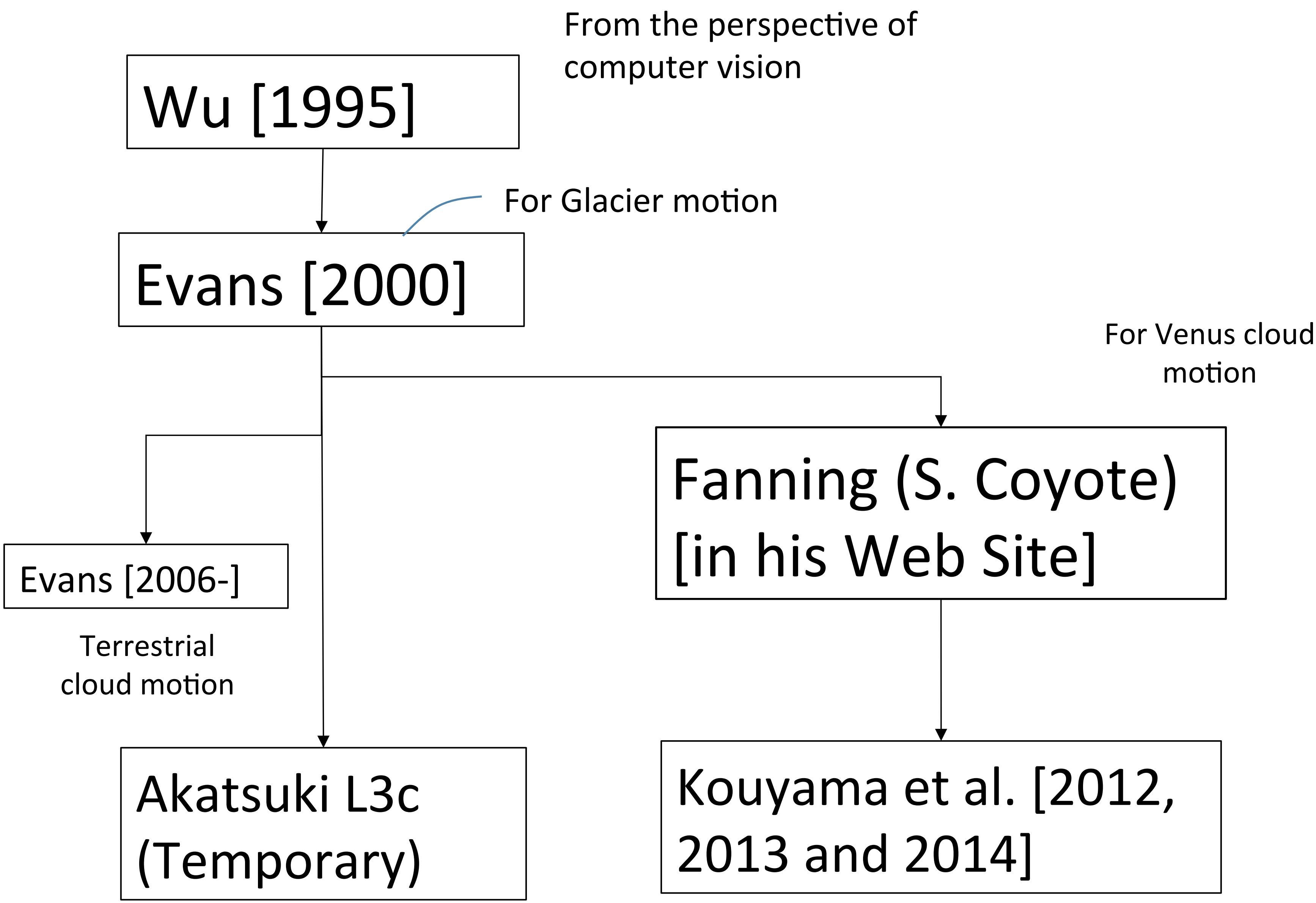


Avoiding to select erroneous vectors





History of Cloud Tracking Technique using Probabilistic Relaxation



[Evans, 2000]

P: Probability(≒Correlation Coeff.)
Q, R: Weighting functions
D: Distance between templates
σ: Scale coefficient

$$P^{(n+1)}(J \to j) = \frac{P^{(n)}(J \to j) Q(J \to j)}{\sum_{\lambda \in \Omega_{2J}} P^{(n)}(J \to \lambda) Q(J \to \lambda)}.$$

$$Q(J \to j) = \prod_{I \in G_j} \sum_{i \in \Omega_{2J}} P^{(n)}(I \to i) R(I, J, i, j).$$

$$R(I, J, i, j) = \exp\left[\frac{|\Delta x_{I,i} - \Delta x_{J,j}|}{\sigma}\right] \cdot \exp\left[\frac{|\Delta y_{I,i} - \Delta y_{J,j}|}{\sigma}\right] D(I, J)$$

Using x and y discrepancy separately

[Fanning version]

p: Probability(≒Correlation Coeff.)
q: Weighting function
d: Distance between templates
σ, g: Scale coefficients

$$p(i) = \frac{p(i) q(i)}{\sum_j p(j) q(j)}$$

(difference of two vectors)^2

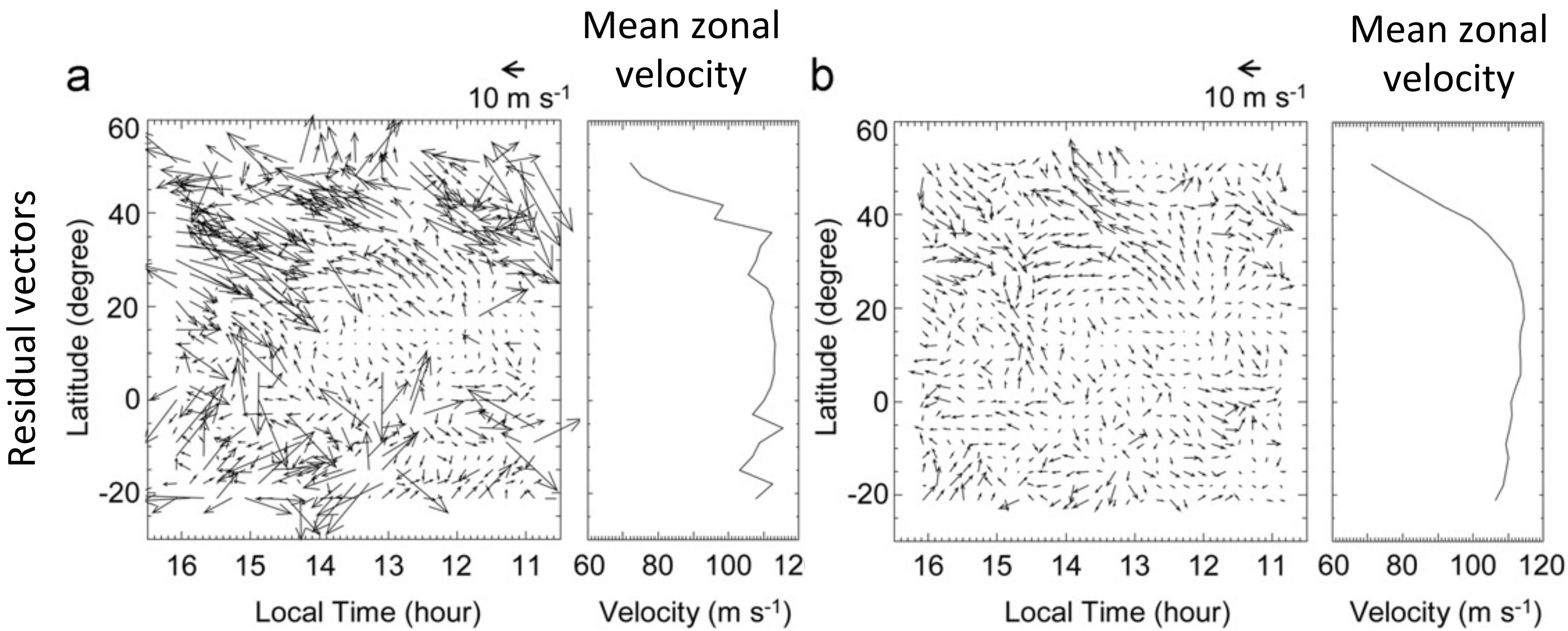
$$q(i) = \sum_n \sum_k p(k) \exp\left[-\frac{|v_n(k) - v(i)|^2}{\sigma^2}\right]\left(\frac{g}{d_n}\right)$$

(after Kouyama et al., 2012)

Result

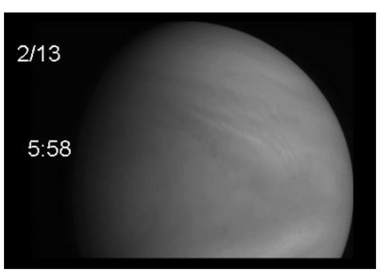
Before

After modification



Using Galileo/SSI data (1990.02.13)

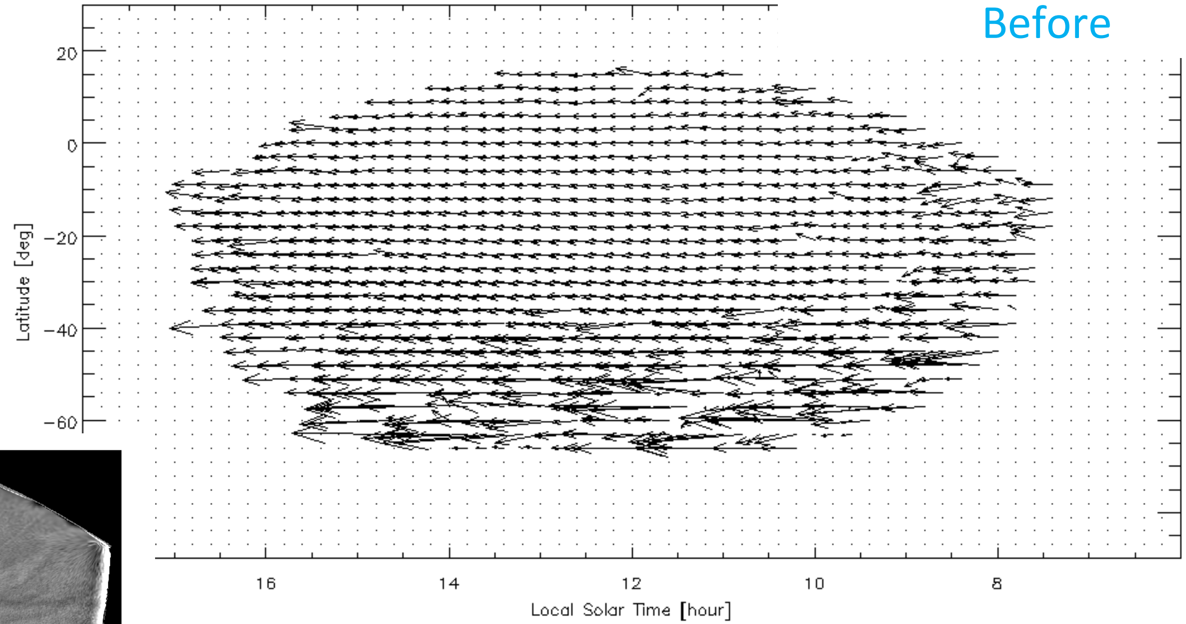
[Kouyama et al., 2011]

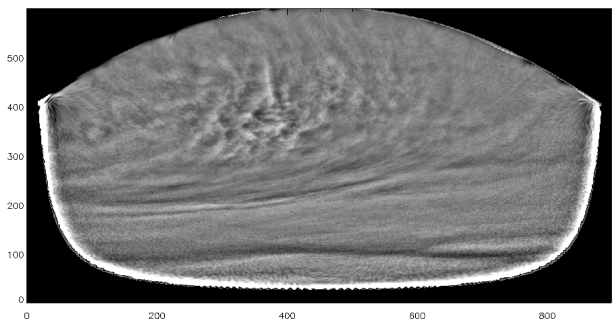


Template size: 6 x 6 degrees
Interval: 3 degrees

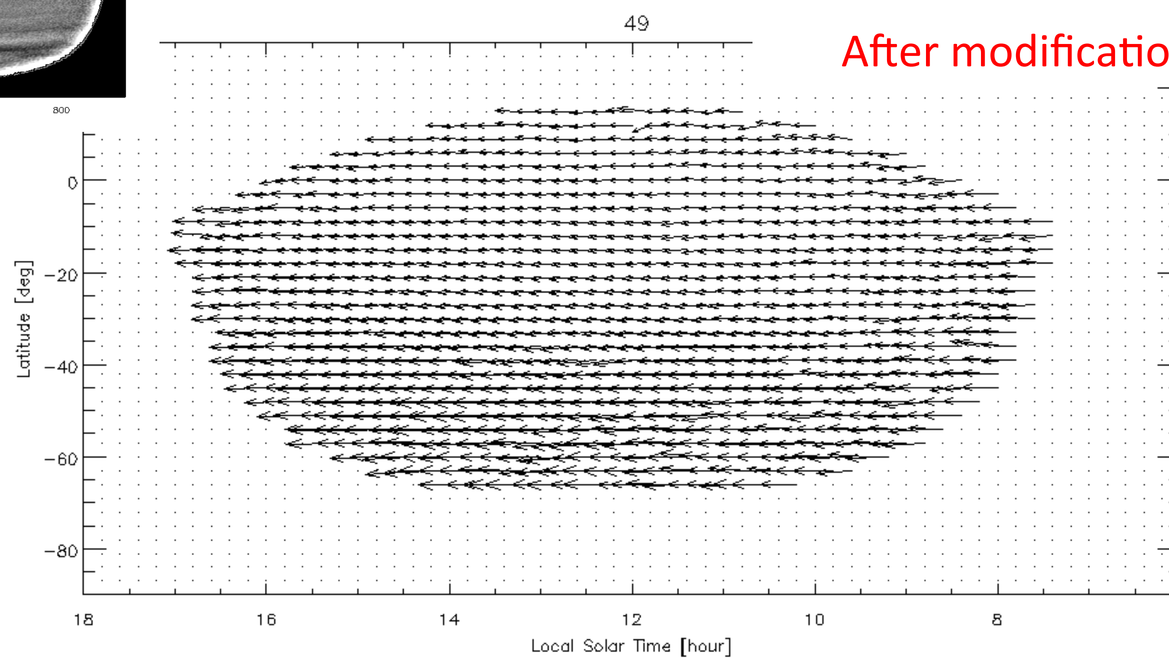
VMC data
Orbit # 0462

Before





After modification

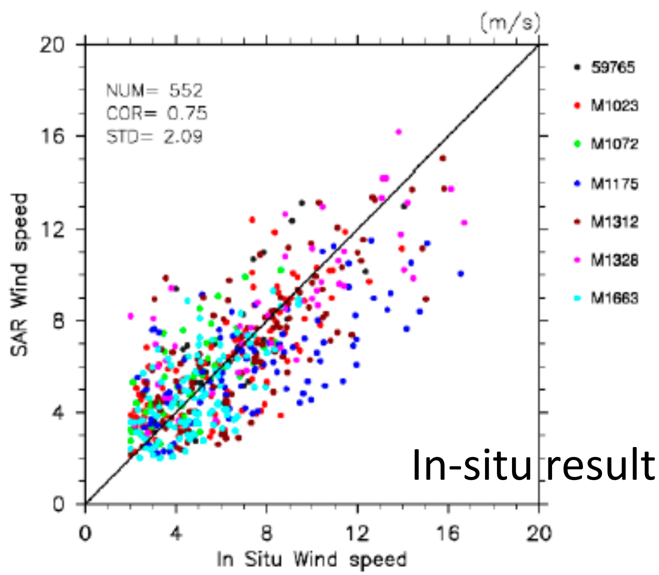


The obtained vector field is reliable?
Concern about the modification method:
Too much modified? Or too less modified?

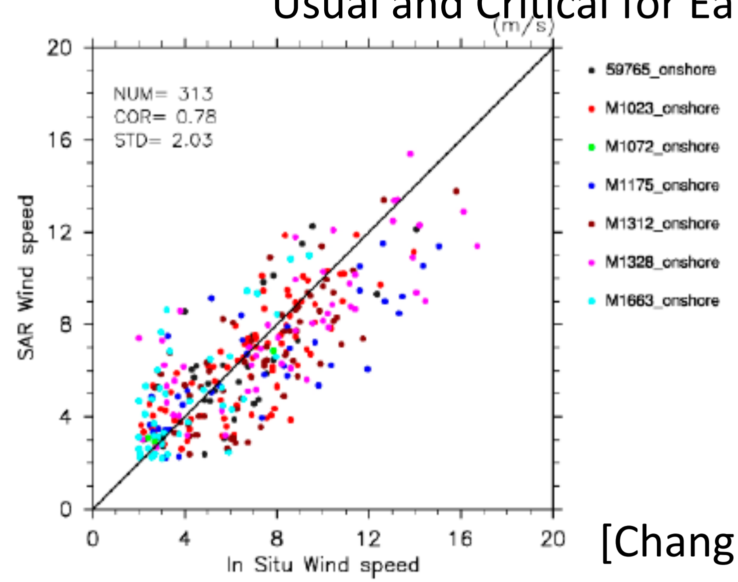
-> Validation is important.
(cf. comparing simultaneous in-situ measurement)

Usual and Critical for Earth science

Remote sensing result



In-situ result



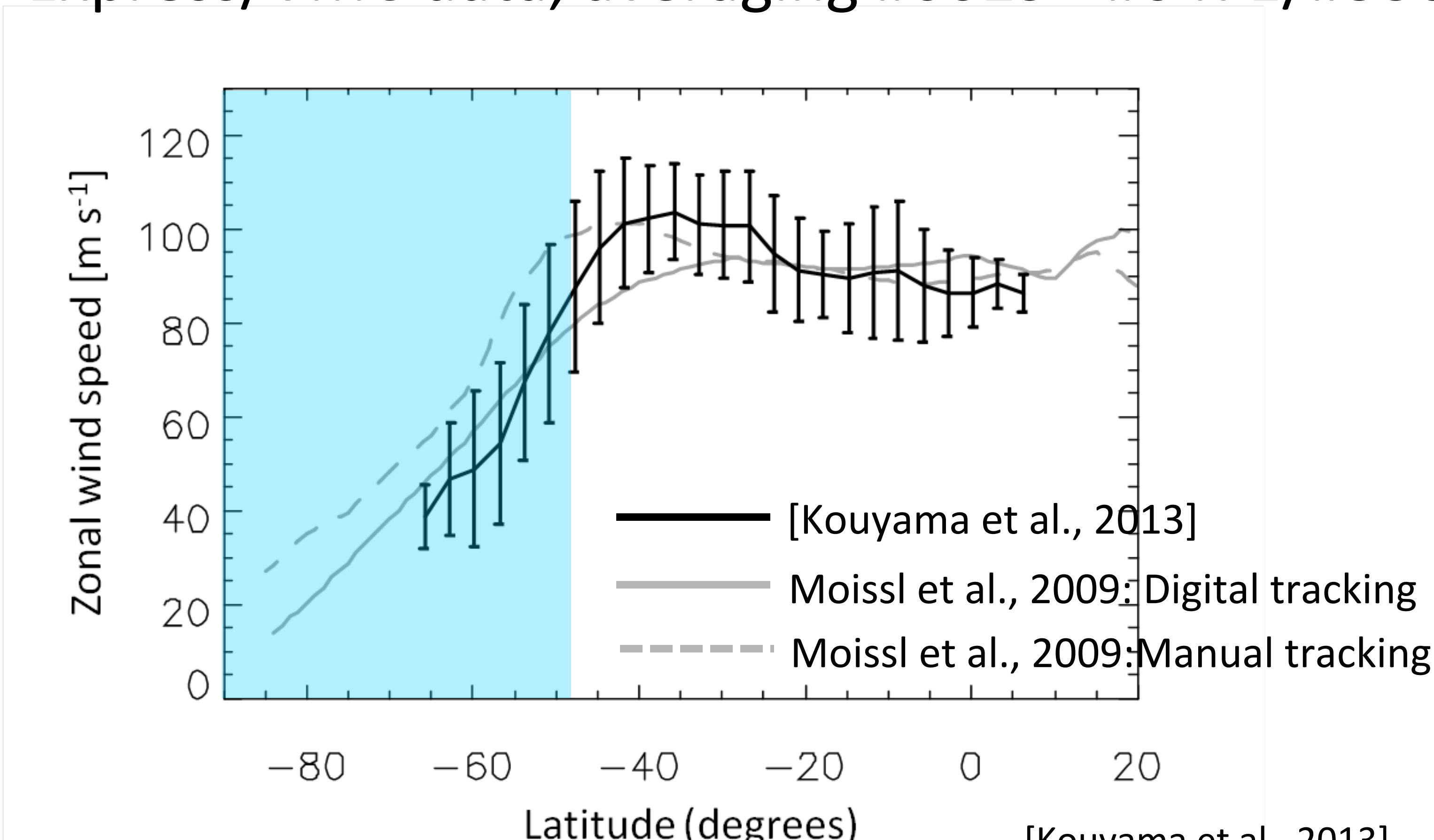
[Chang et al., 2015]

However:
Simultaneous in-situ measurement is difficult at Venus, and so far we have not had such data set.

Therefore:
Consistency with manual tracking (and also other cloud tracking techniques, other measurements) is essential at first for a digital cloud tracking technique.

Future work:
Integration of results
Data assimilation…

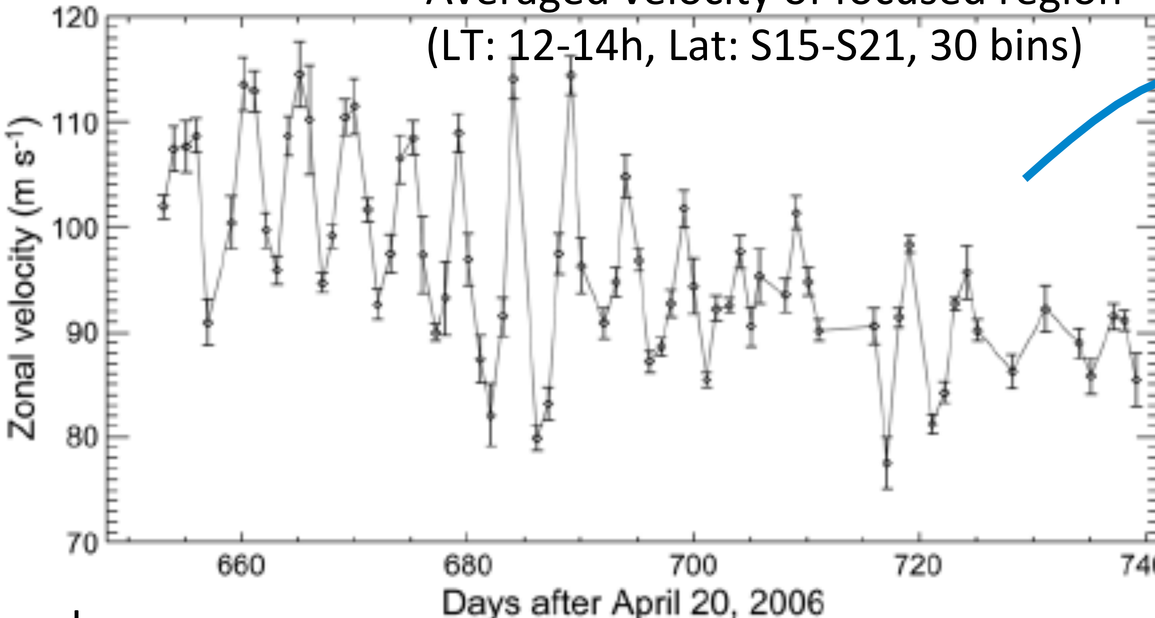
Comparison between manual and digital tracking results (Venus Express/VMC data, averaging #0029 - #0471/#530)

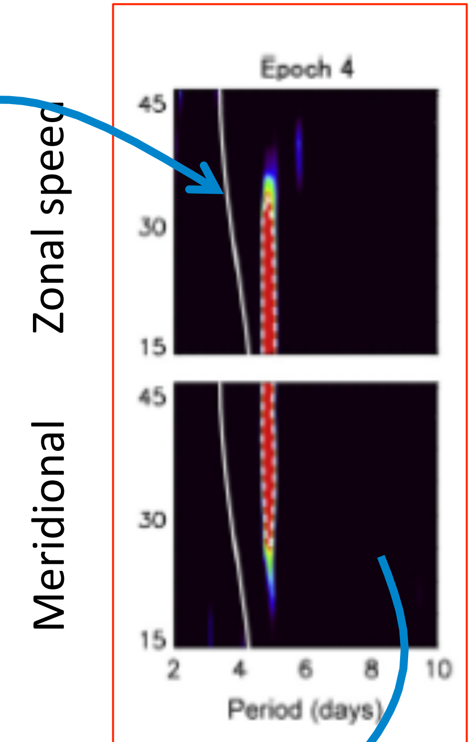


[Kouyama et al., 2013]

Error bars indicate standard deviation of zonal speed at each latitude bin.
These include spatial structures of thermal tides and temporal variation during the period.
Moissl et al., 2009 showed similar magnitude of error.

Averaged velocity of focused region
(LT: 12-14h, Lat: S15-S21, 30 bins)

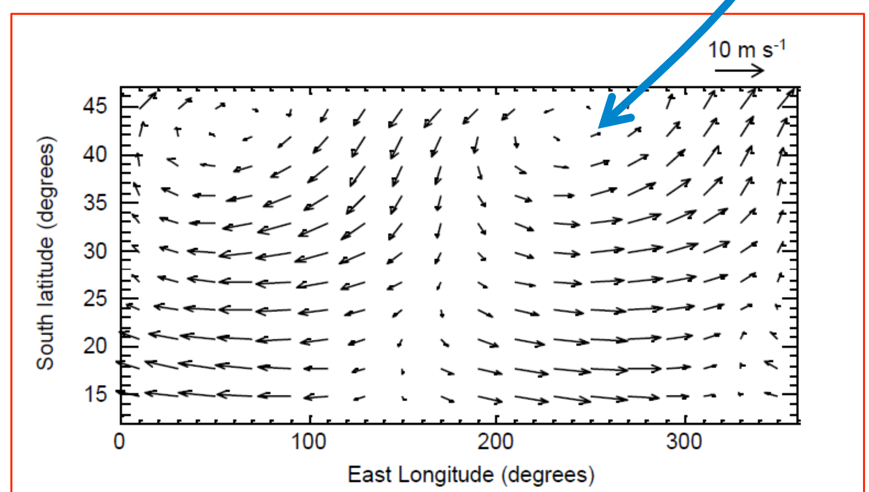




Error bar:
Standard error of the focused region
+ Expected limb fitting error (~2m/s)
(+ Real spatial structure of wind field, not included yet)

We can recognize a clear periodical perturbation with 5-10 m/s amplitude .

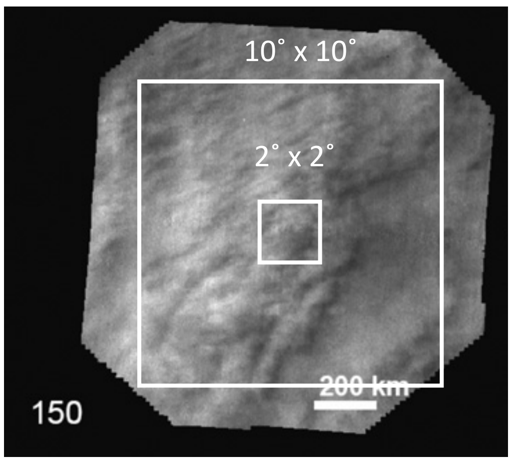
We can retrieve Rossby wave-like signature from the characteristics of the perturbation.

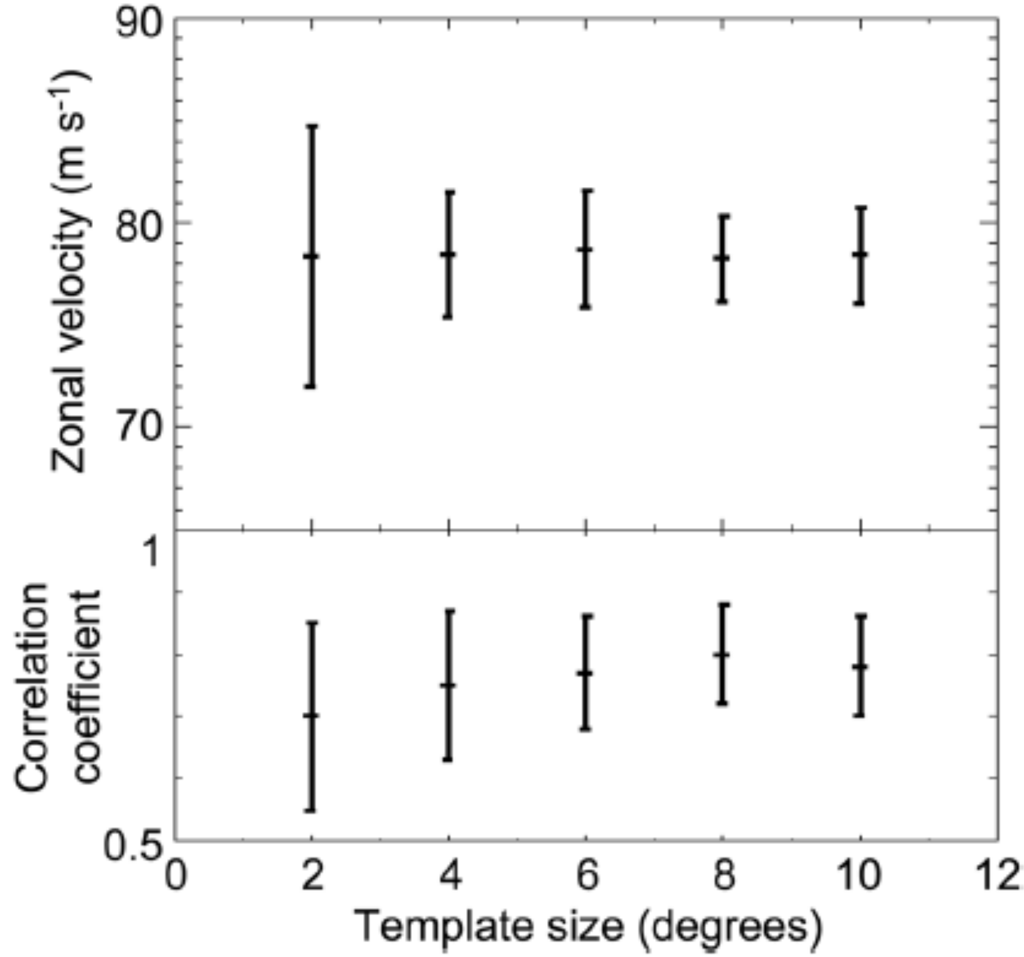


[Kouyama et al., 2013]

Discussion topics
- Template size

In a certain template size range, cloud motion velocity does not show template size dependency.





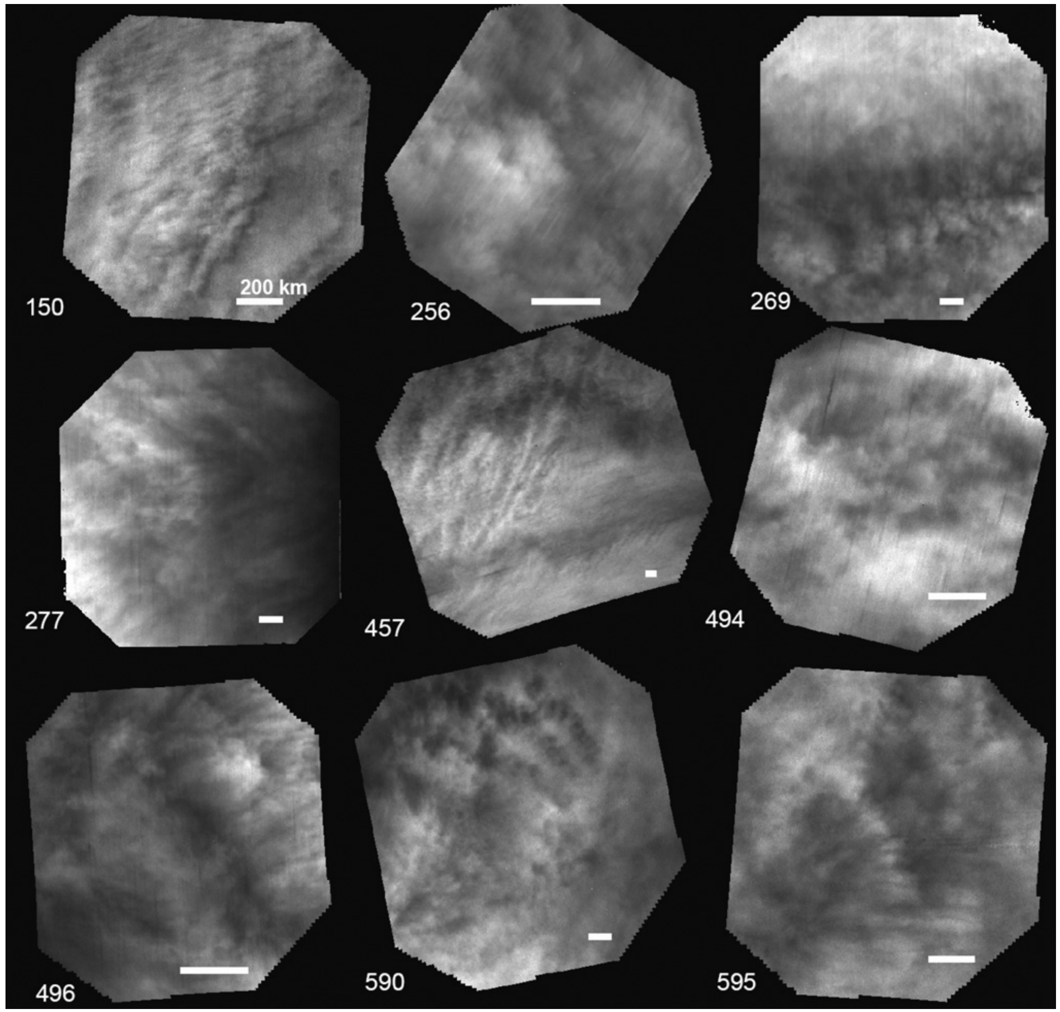
1 degree ~ 100 km @ equator

[Kouyama et al., 2013]

Discussion topics
- Template size

In a certain template size range, cloud motion velocity does not show template size dependency.

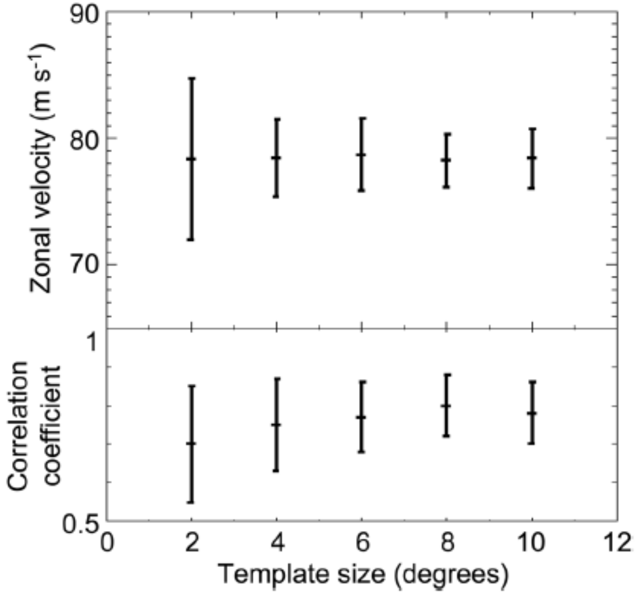
What features do we track ?

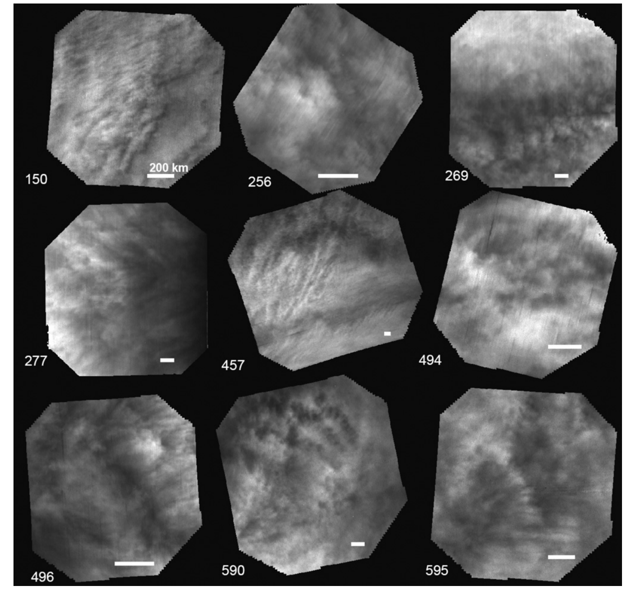


1 degree ~ 100 km @ equator

[Titov et al., 2012]

Basically same velocity from various template sizes





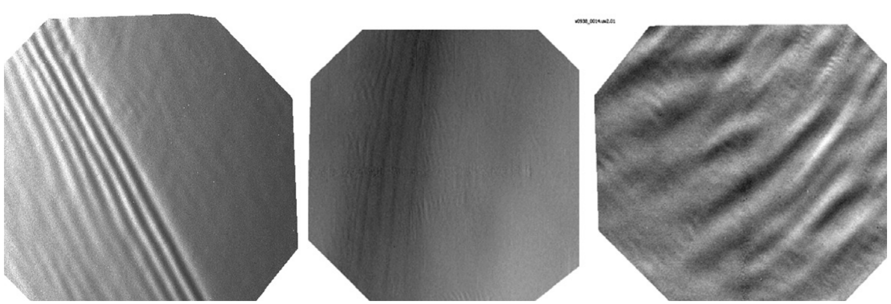
But we should consider…

Smaller scale <-

Small scale gravity wave patterns:

Phase velocity ≠ Actual wind velocity

Convective cells:

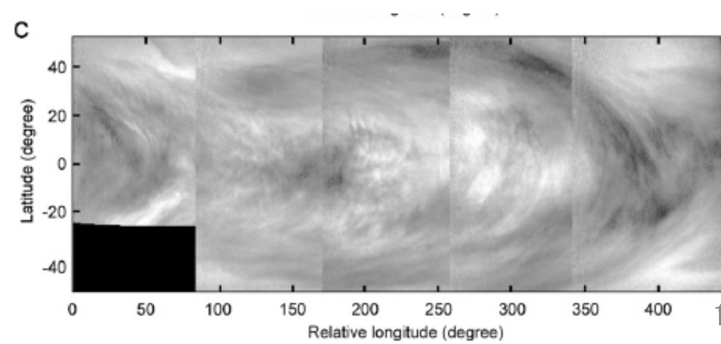


[Titov et al., 2012]

-> Larger scale

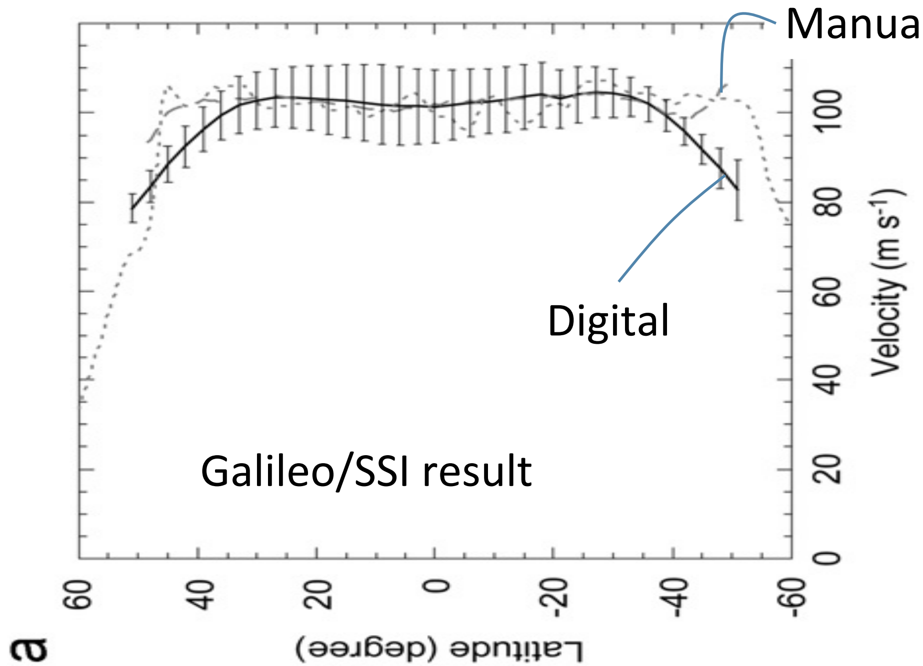
Huge scale patterns:

- Y-shape pattern
- Planetary-scale waves

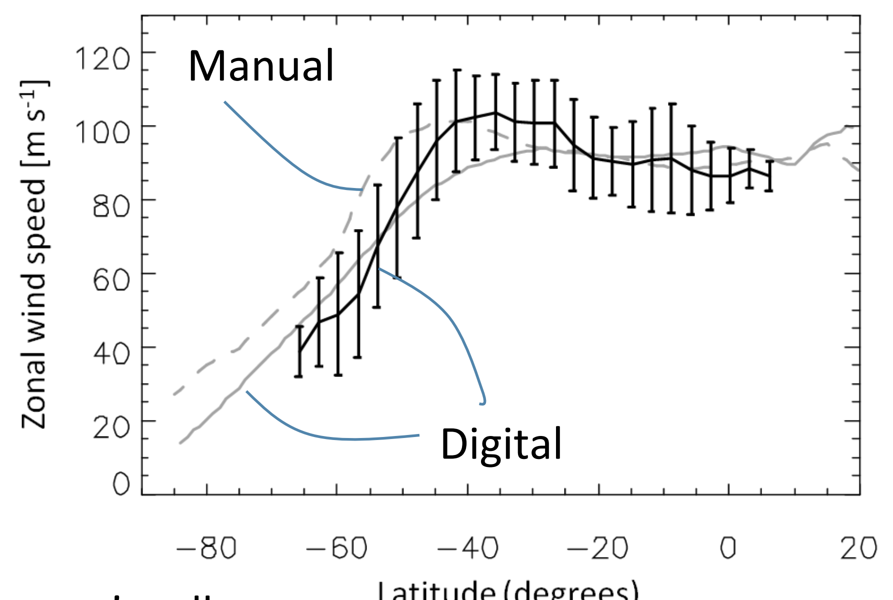


Discussion topics

- Difficulty of CT in Middle and High latitudes



In mid-high latitudes, zonal speed from digital tracking is always lower than manual tracking.

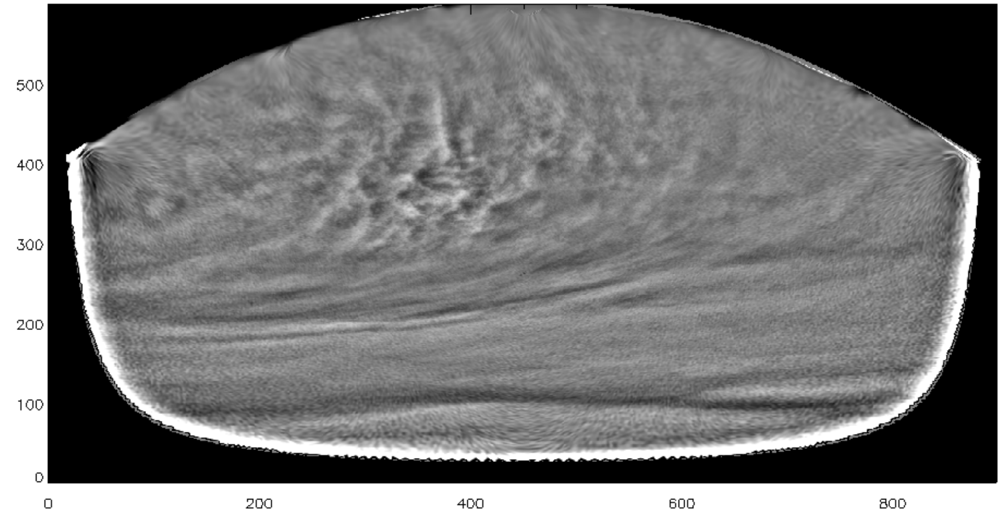


Traditional question.
But the reason has been still unclear…

I think detail discussion is in Ogohara-san's talk tomorrow

Discussion topics

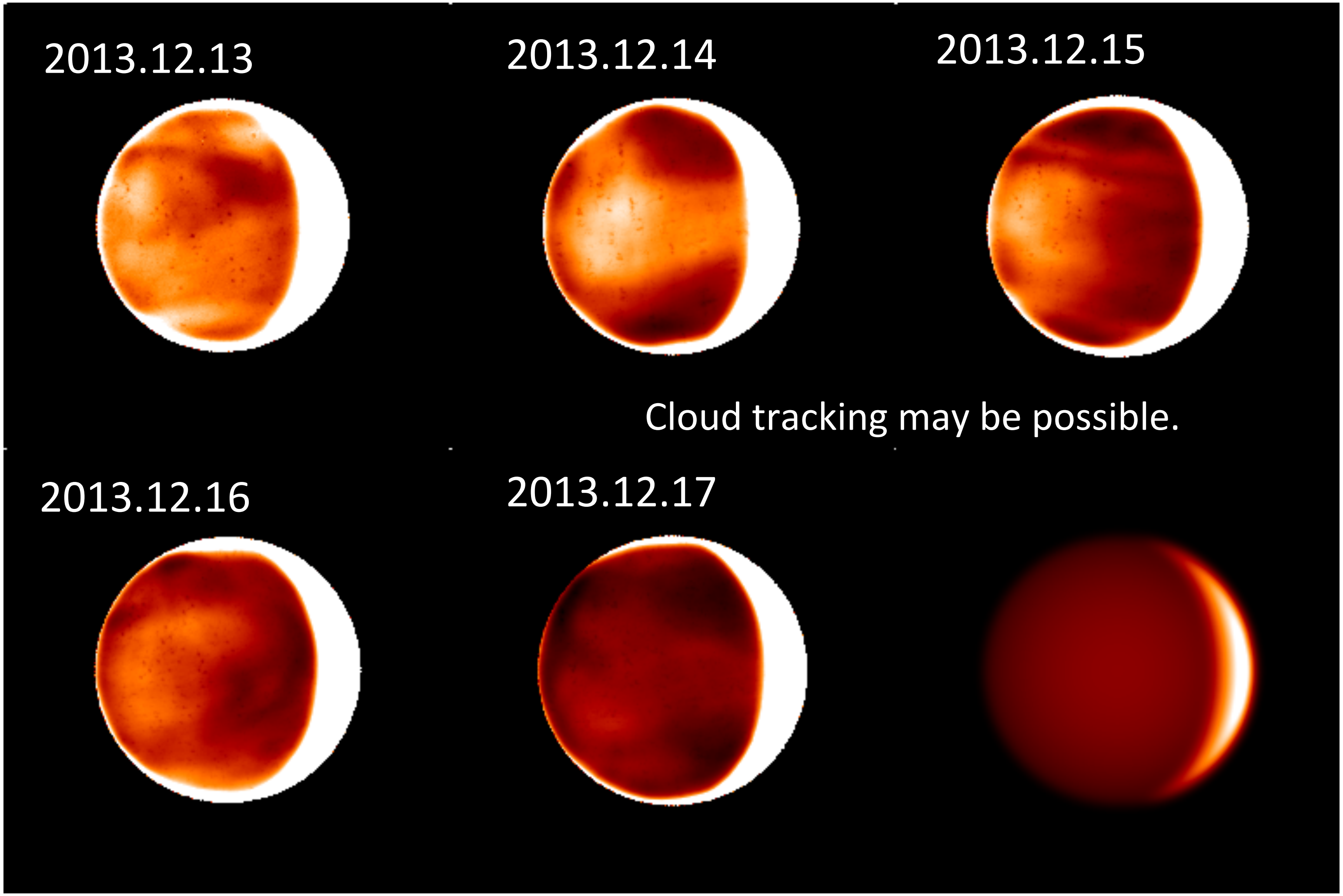
- Difficulty of CT in Middle and High latitudes



- Streak patterns => aperture problem
- Less features
- Highly distorted (expanded) by the projection onto longitude-latitude coordinate in Akatsuki L3 case

Preparing other projection (ex. Polar Stereo) is worth considering?

Groud-based observation: 4.6 um Night side



NASA/IRTF NSFCam2
@ 4.6μm

Next 4um observation in Next July with IRTF/SPeX