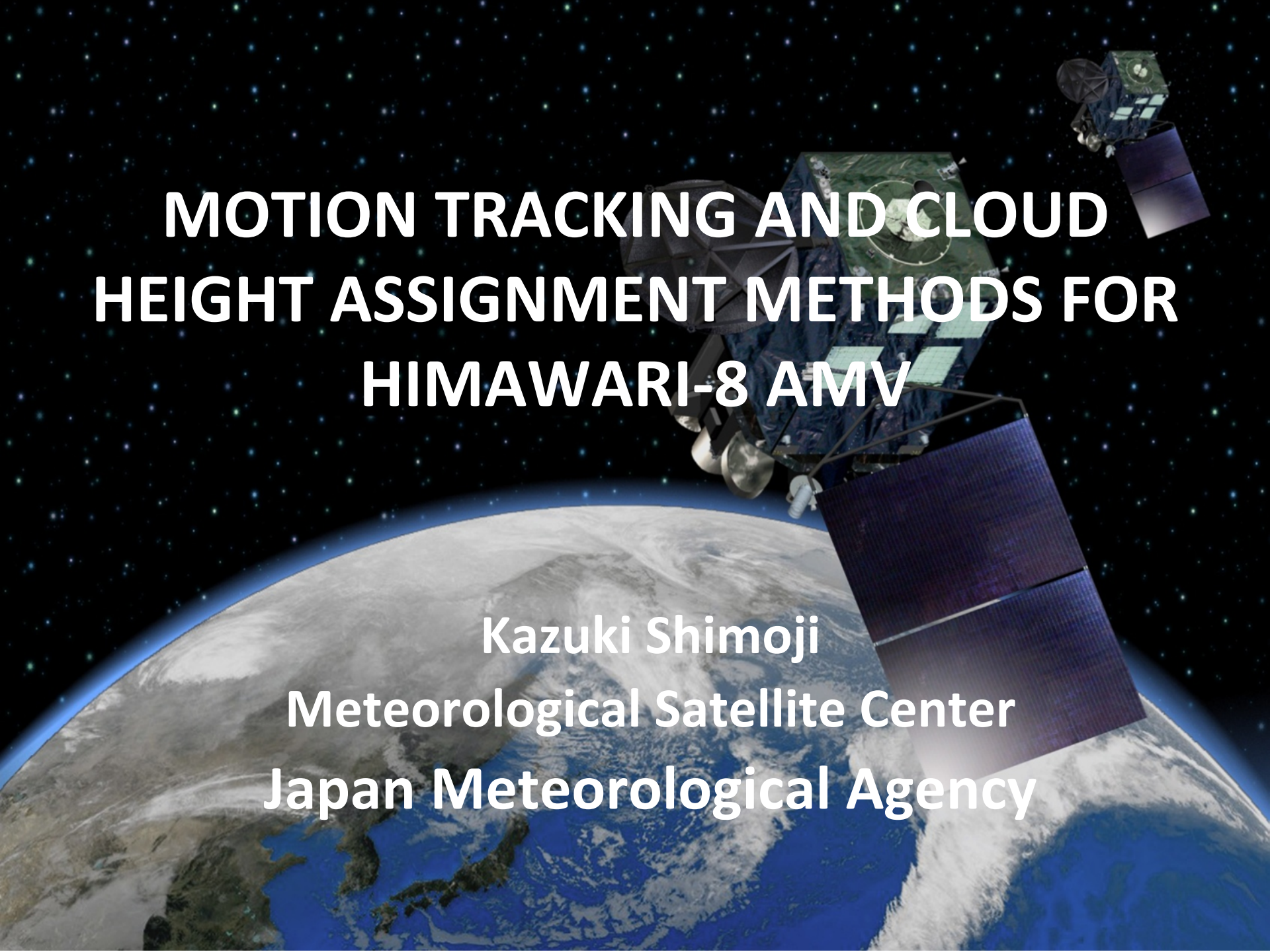

MOTION TRACKING AND CLOUD HEIGHT ASSIGNMENT METHODS FOR HIMAWARI-8 AMV

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Japan Meteorological Agency

Contents

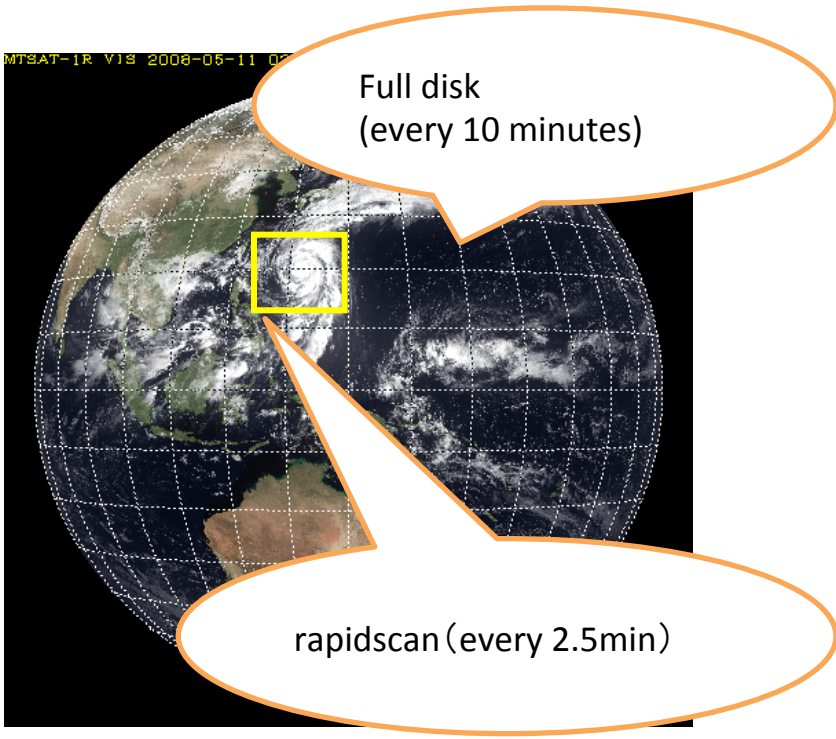
1. Introduction to Advanced Himawari Imager (AHI)
2. Tracking algorithm
3. Cloud height assignment algorithm
4. Result by new algorithm
5. Summary

Specification of Advanced Himawari Imager (AHI)

HIMAWARI-8/9

Band	Central Wavelength [μm]	Spatial Resolution
1	0.43 - 0.48	1Km
2	0.50 - 0.52	1Km
3	0.63 - 0.66	0.5Km
4	0.85 - 0.87	1Km
5	1.60 - 1.62	2Km
6	2.25 - 2.27	2Km
7	3.74 - 3.96	2Km
8	6.06 - 6.43	2Km
9	6.89 - 7.01	2Km
10	7.26 - 7.43	2Km
11	8.44 - 8.76	2Km
12	9.54 - 9.72	2Km
13	10.3 - 10.6	2Km
14	11.1- 11.3	2Km
15	12.2 - 12.5	2Km
16	13.2 - 13.4	2Km

RGB



Band	Central Wavelength [μm]	Spatial Resolution
1	0.55 – 0.90	1Km
2	3.50 – 4.00	4Km
3	6.50- 7.00	4Km
4	10.3 – 11.3	4Km
5	11.5 – 12.5	4Km

MTSAT-1R/2

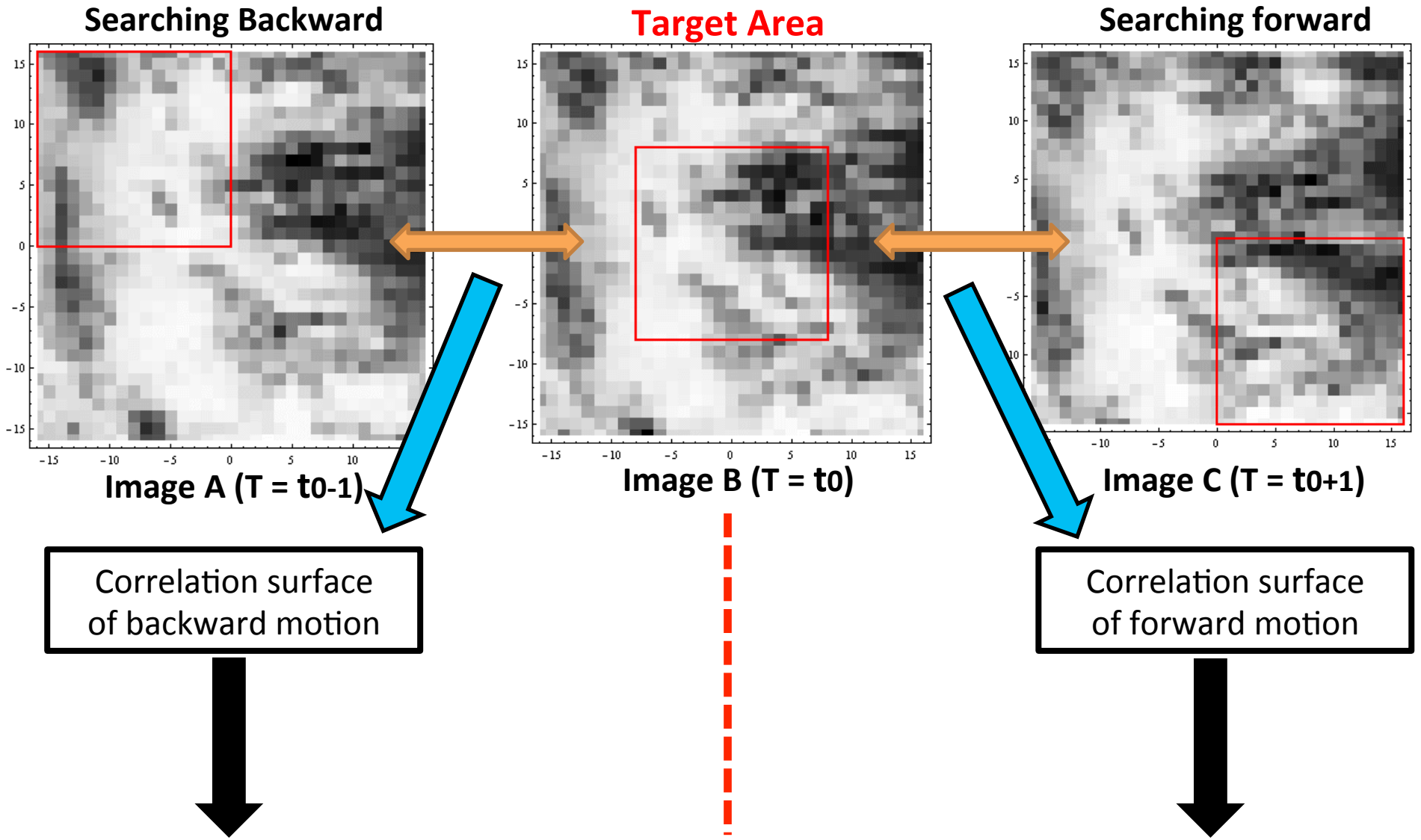
motivation to innovate new tracking and height assignment method

- Effective use of increased temporal and spatial information
  = higher resolution AMV requested
  = target box size should be minified for avoiding overlapping
  = **tracking accuracy debased due to lack of target feature information**

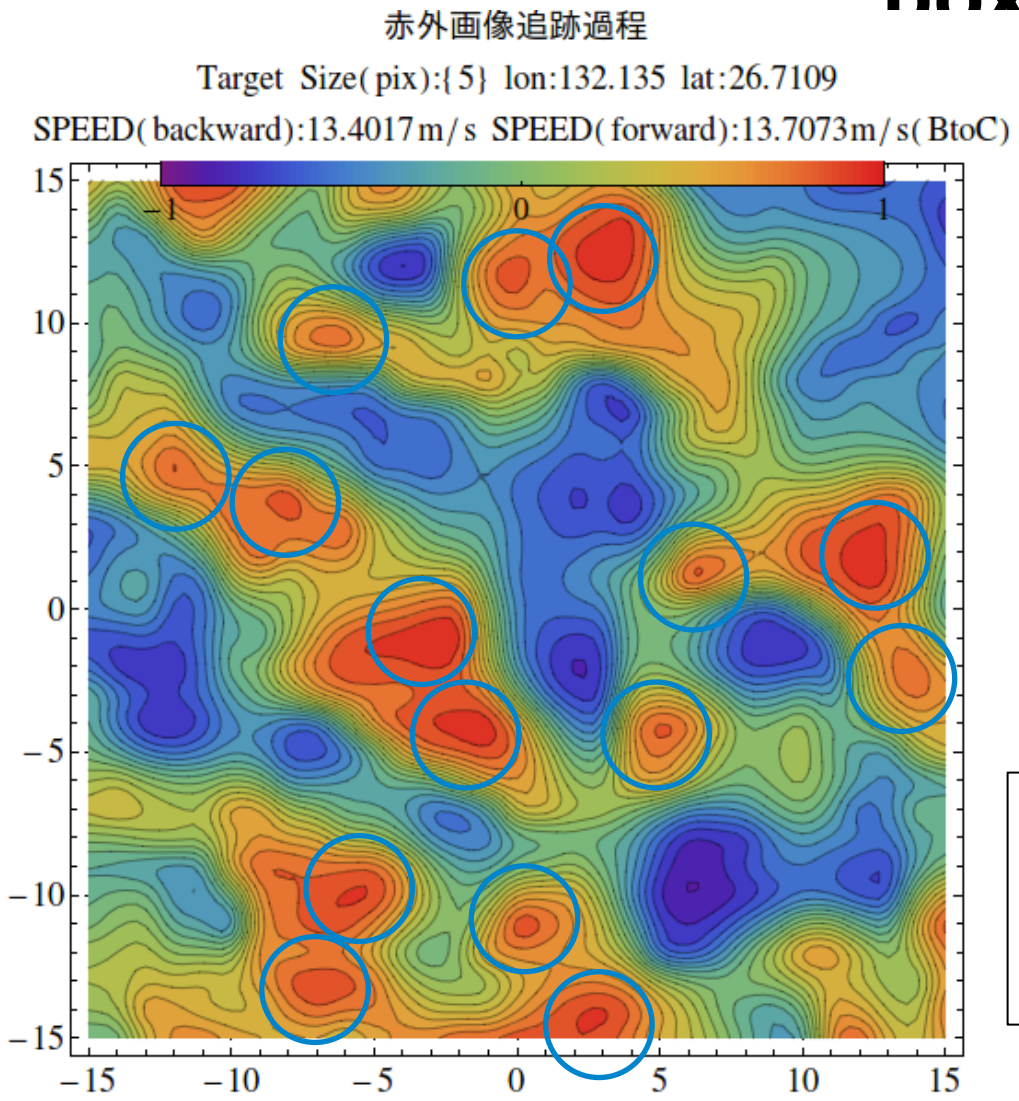
- Effective use of increased bands information
  = improvement to CTH estimation
  = simultaneous use of multiple bands needed
  = **JMA has no methods better than IR-WV intercept and EBBT for CTH estimation**

Contents

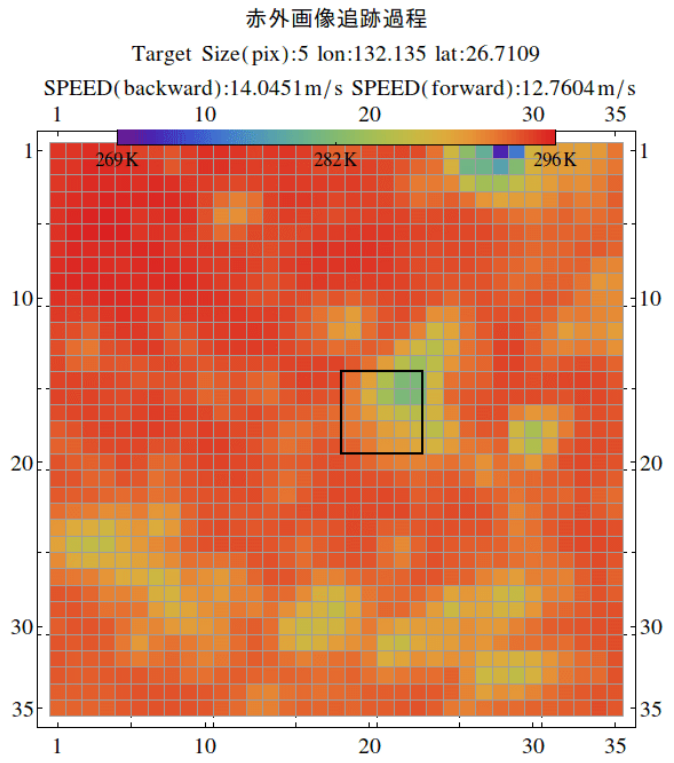
Cross-Correlation Tracking for MTSAT AMV



Correlation Surface from small target box

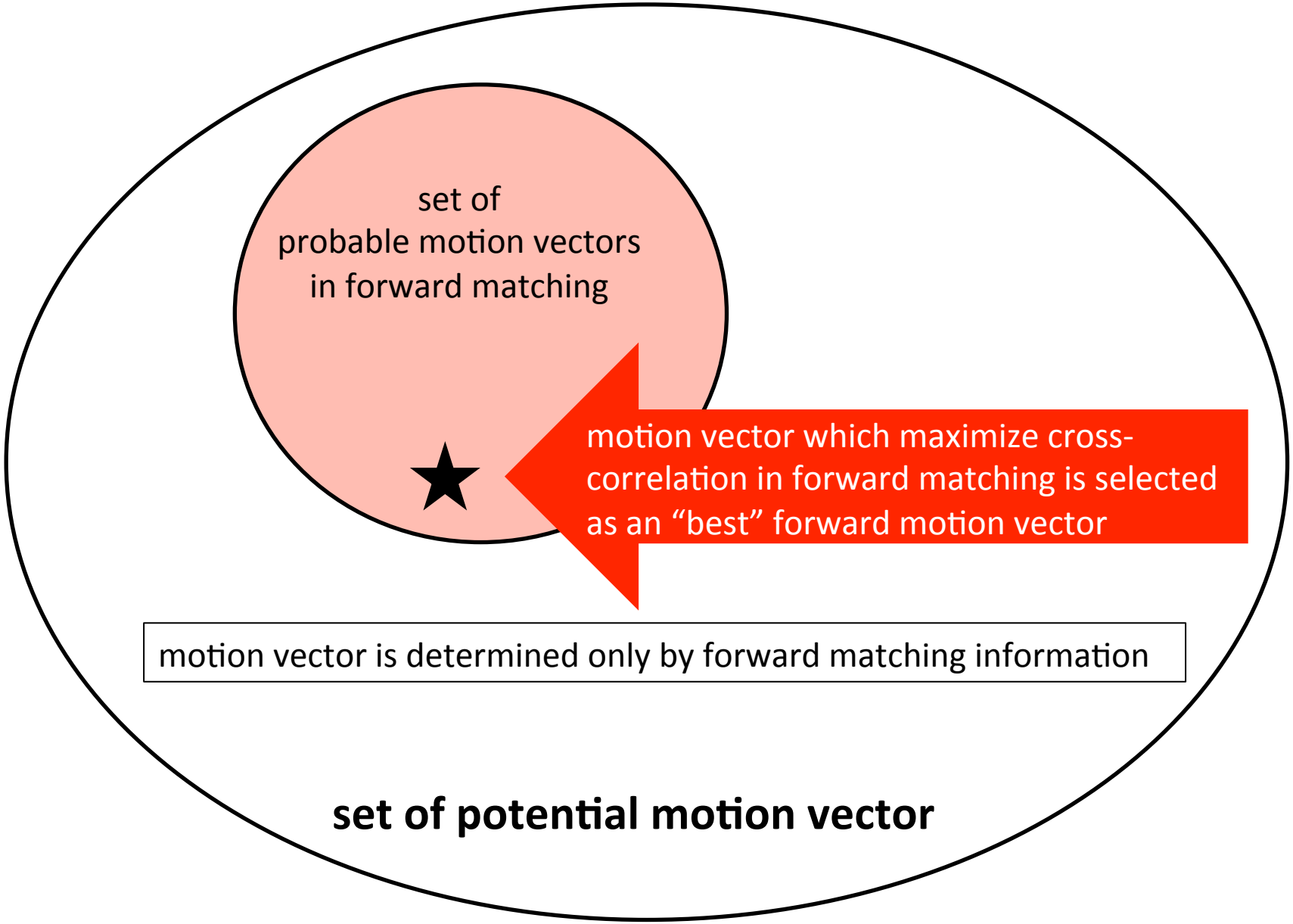


correlation surface with small target box (5x5 pixels)

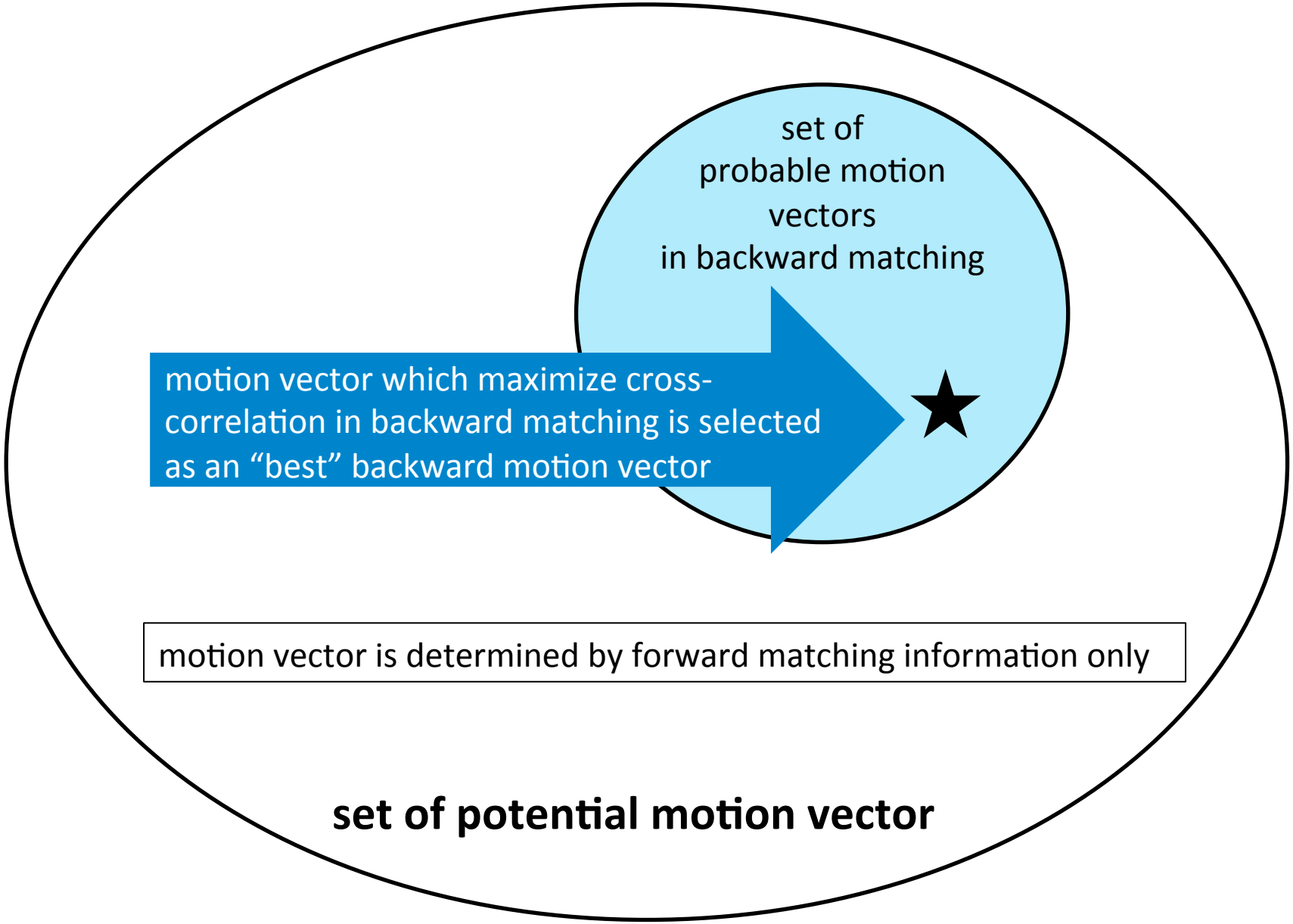


many peaks = many similar patterns -> Information included in target feature is not enough to determine wind vector accurately.

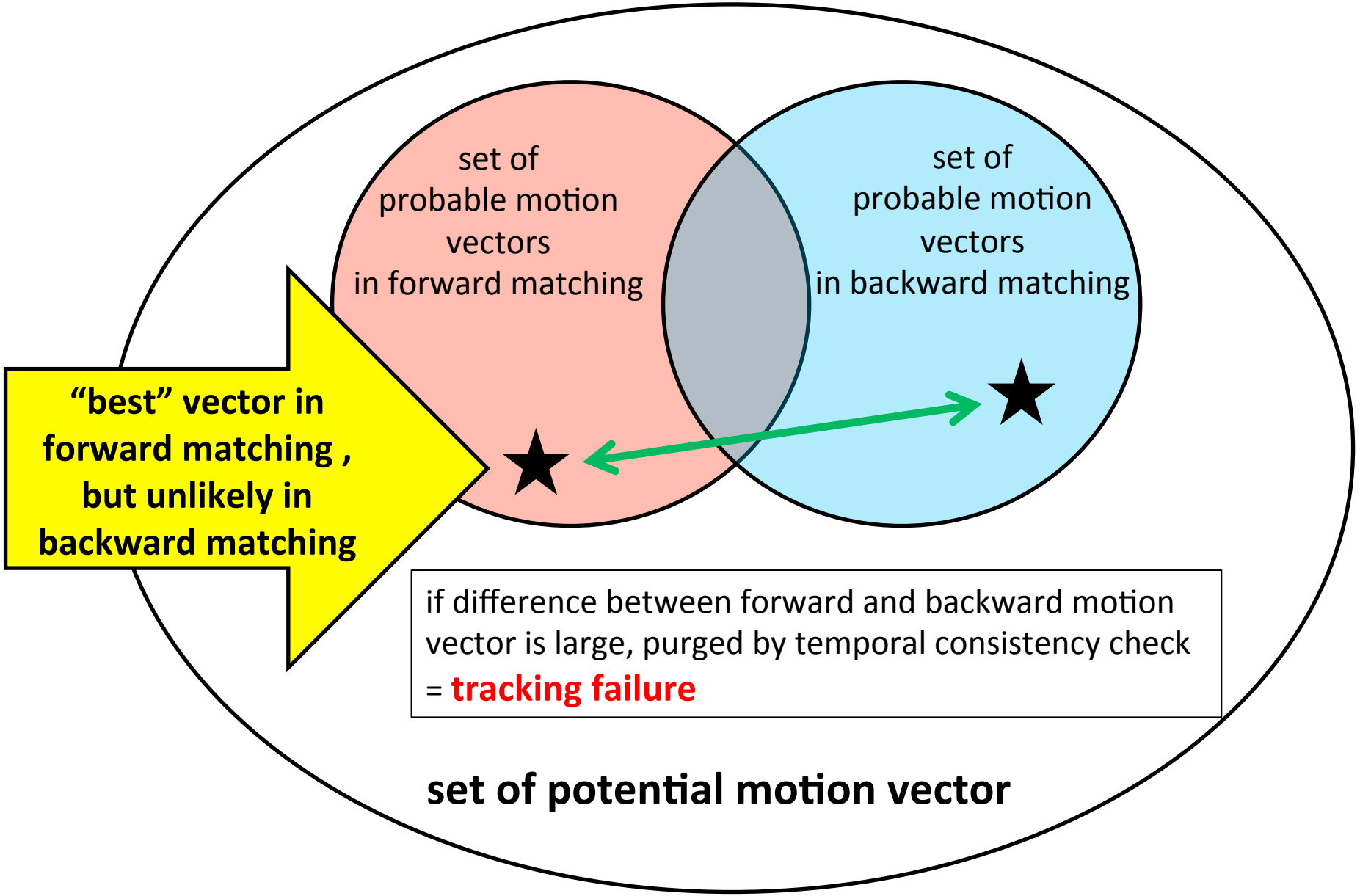
motion vector estimation from forward matching



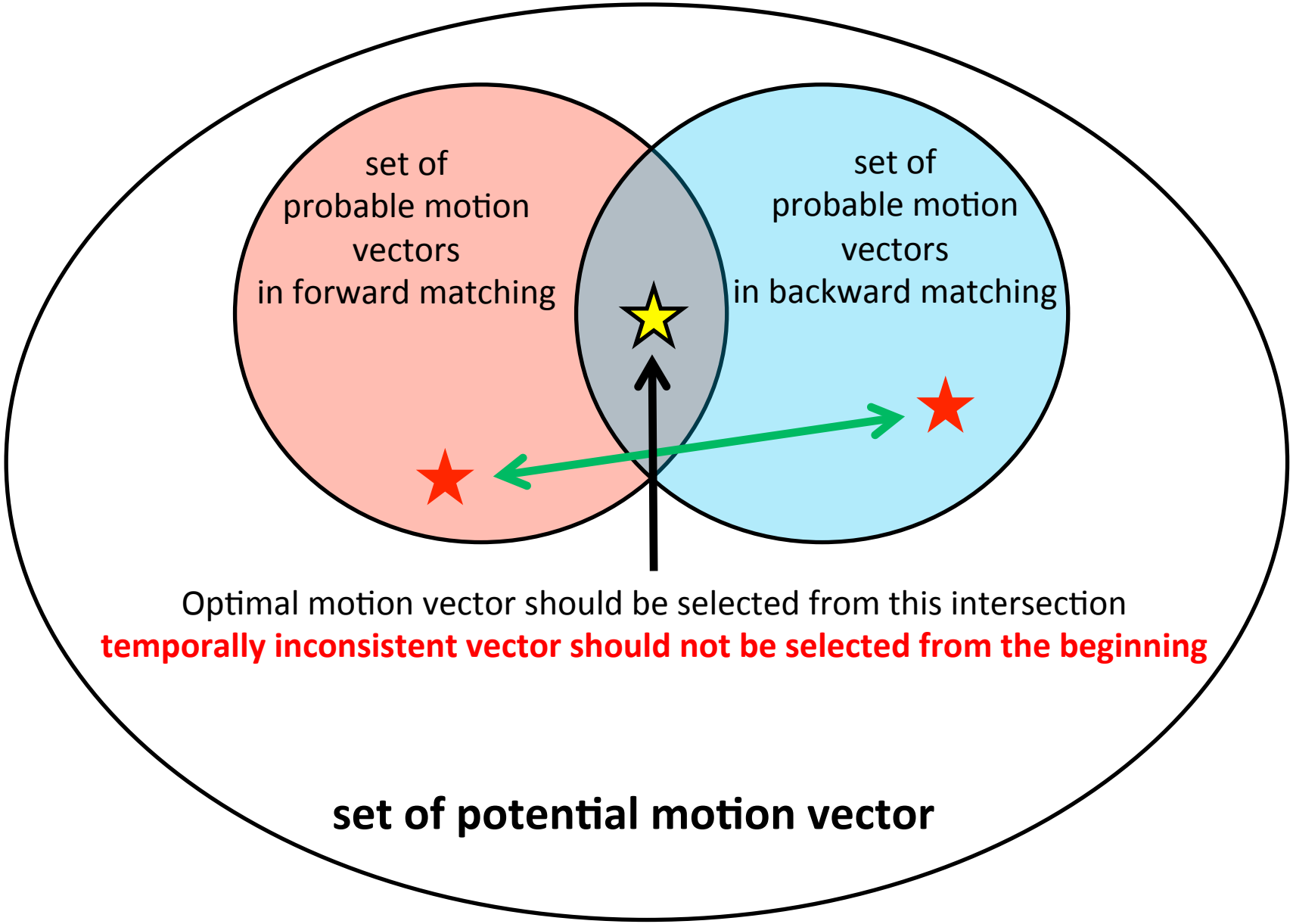
motion vector estimation from backward matching



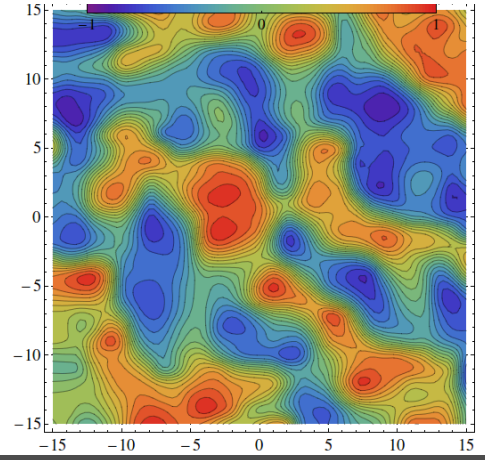
Simultaneous use of matching information



Simultaneous use of matching information

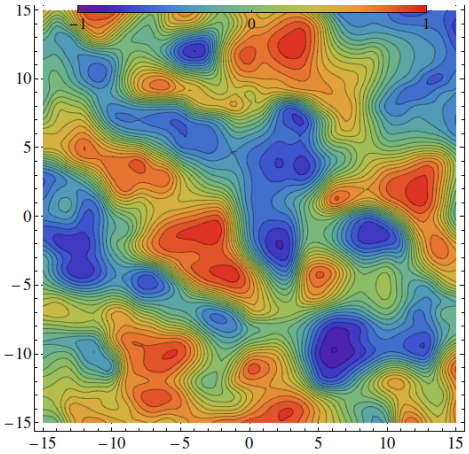


Maximum Likelihood Estimation Approach for small Scale AMV



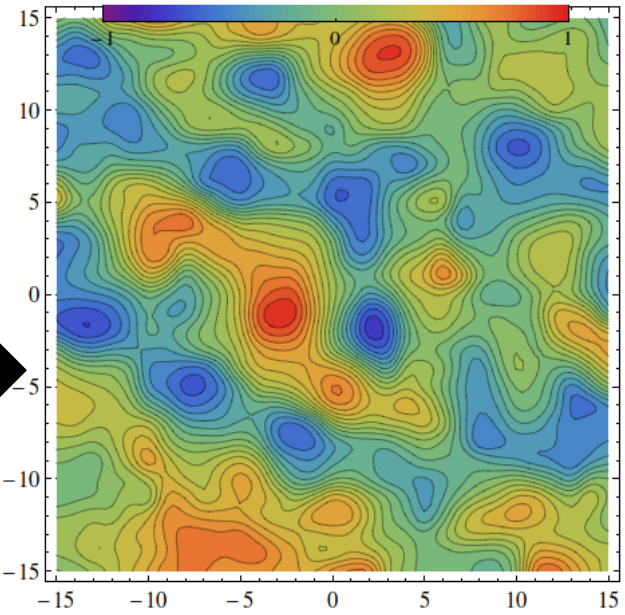
auxiliary information
Correlation surface from backward motion

1. To equate cross-correlation with log likelihood function
2. To compute average of two log likelihood function surface from forward and backward matching
3. To search vector which maximize the averaged log likelihood function



prior information
Correlation surface from forward motion

probabilistic inference
to regard correlation surface as log likelihood function



posterior information
averaged correlation surfaces

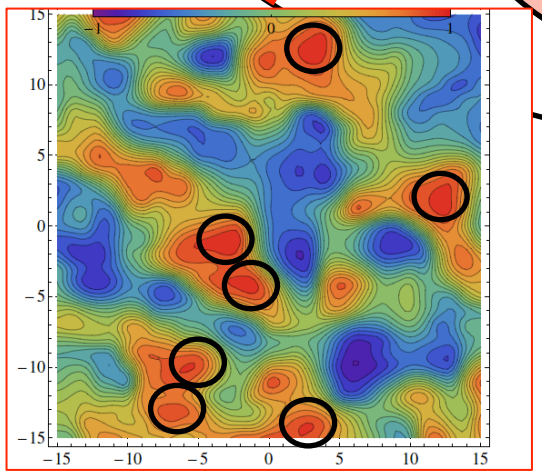
how to find temporally consistent vector

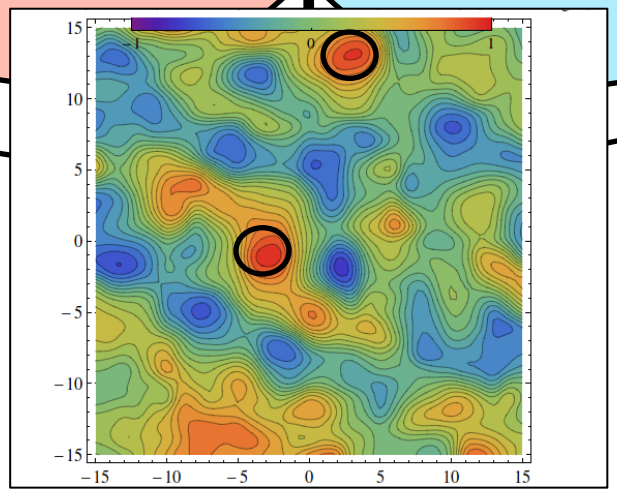
set of potential motion vector

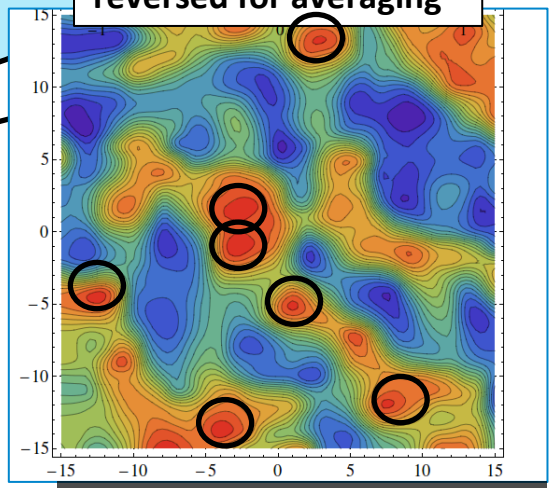
set of
probable motion
vectors
in forward matching

set of
possible backward
motion vectors

reversed for averaging







prior information
correlation surface from
forward matching

posterior information
averaged correlation surfaces

auxiliary information
correlation surface from
backward matching

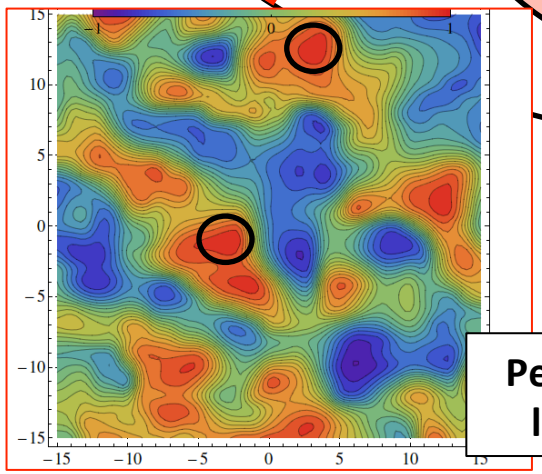
how to search temporally consistent vector

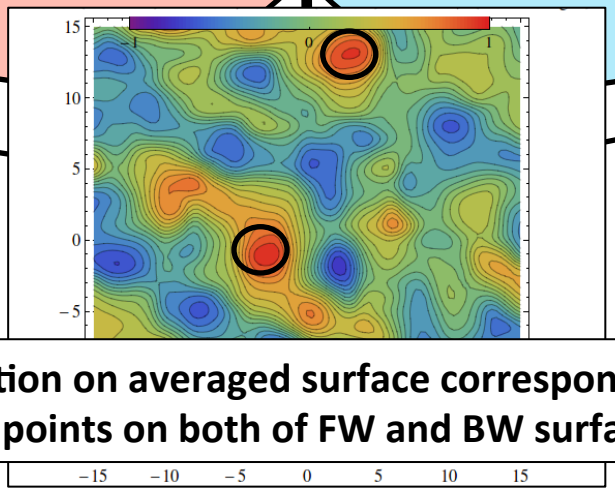
set of potential motion vector

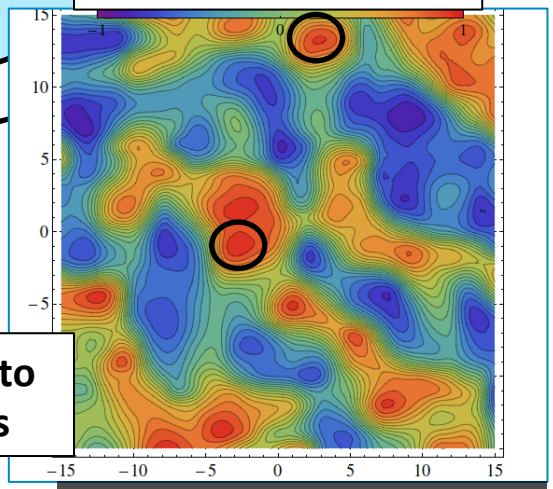
set of
probable motion
vectors
in forward matching

set of
possible backward
motion vectors

reversed for averaging







Peak position on averaged surface corresponds to large CC points on both of FW and BW surfaces

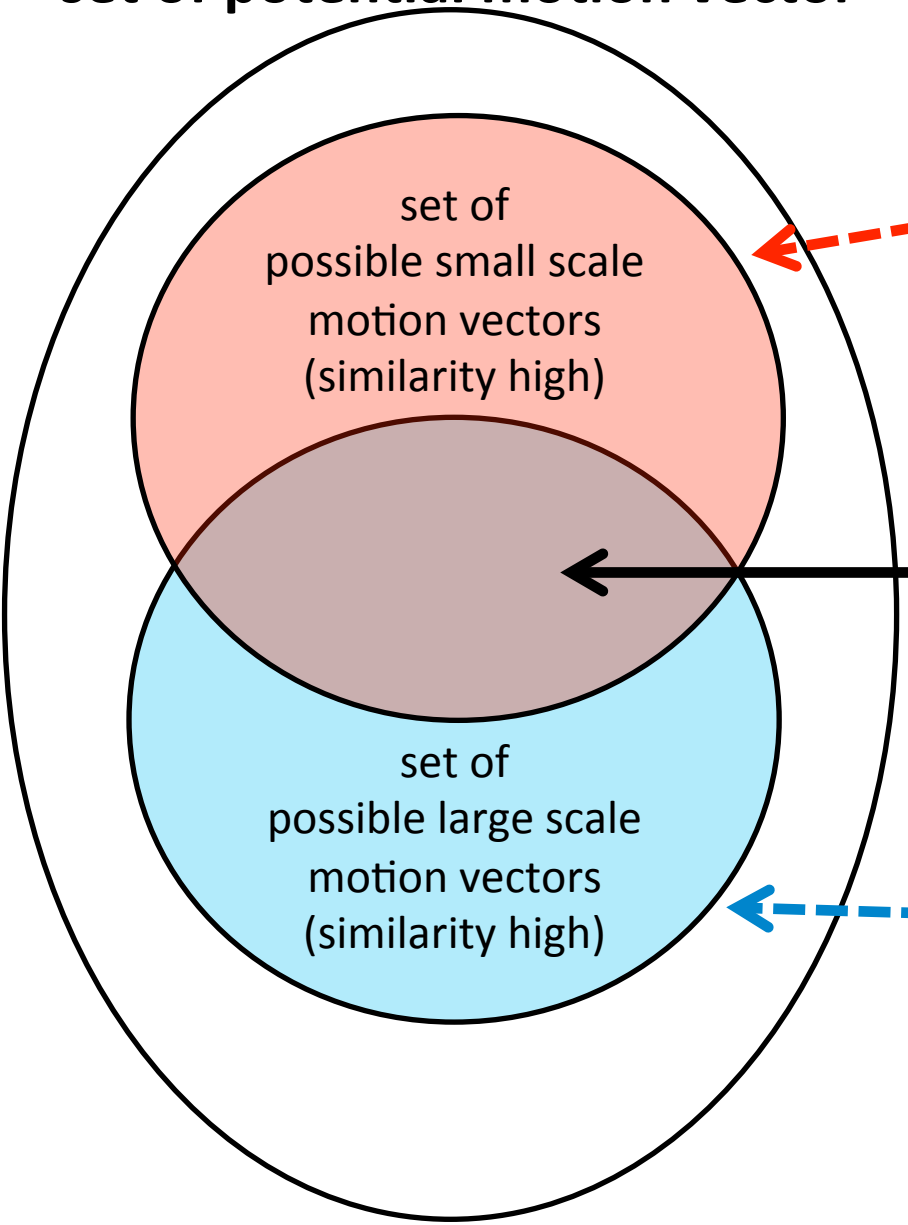
prior information
correlation surface from forward matching

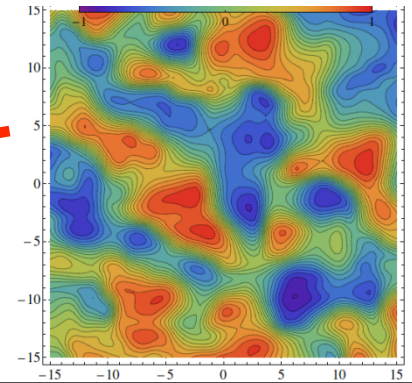
posterior information
averaged correlation surfaces

auxiliary information
correlation surface from backward matching

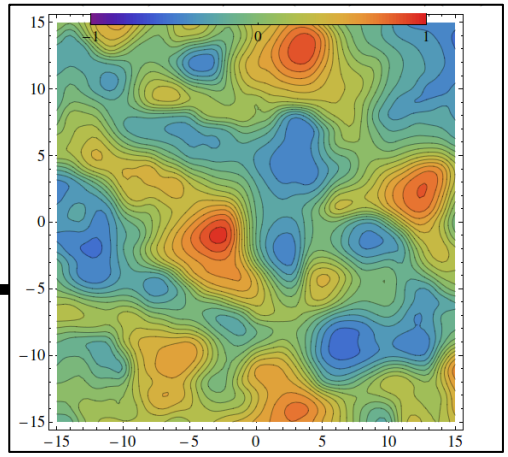
Application to spatially consistent vector

set of potential motion vector

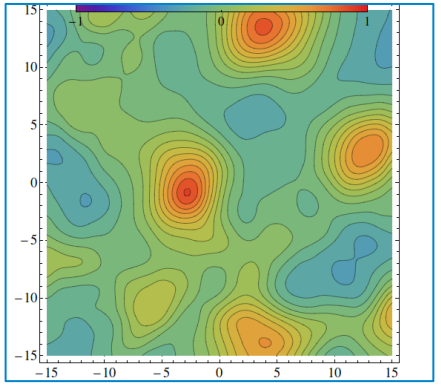




prior information
correlation surface
from small target box

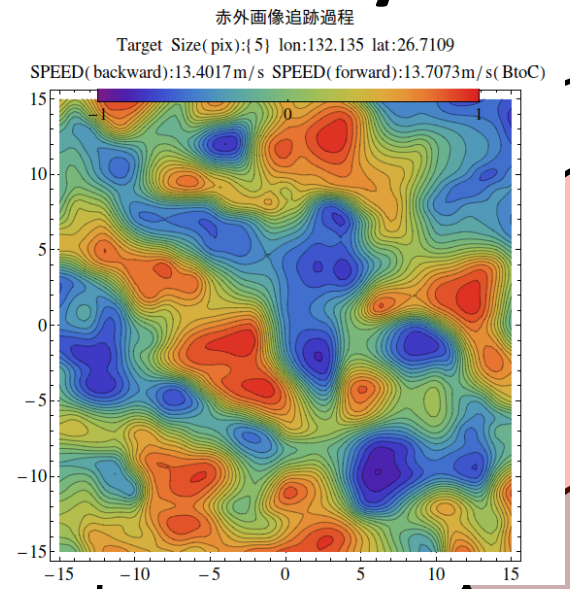


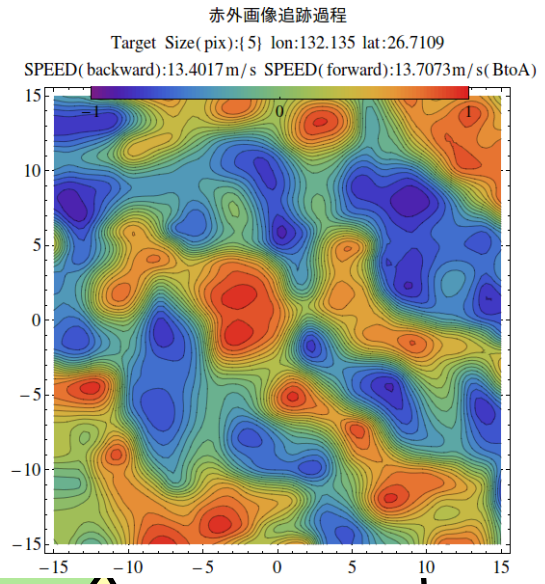
posterior information
averaged correlation surfaces



auxiliary information
correlation surface
from large target box

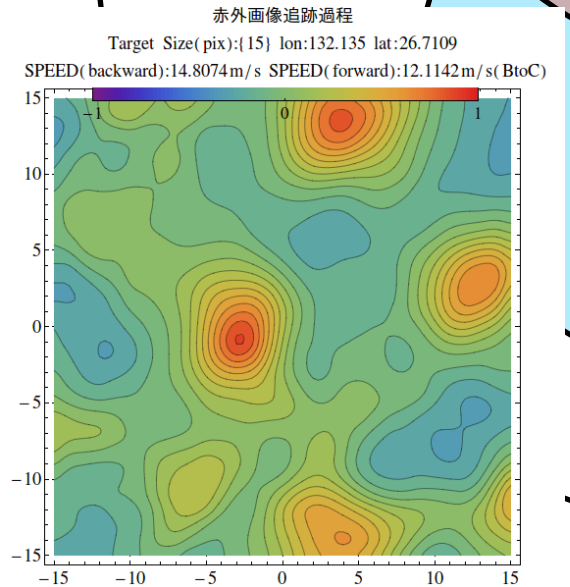
Likelihood estimation by temporal and spatial information





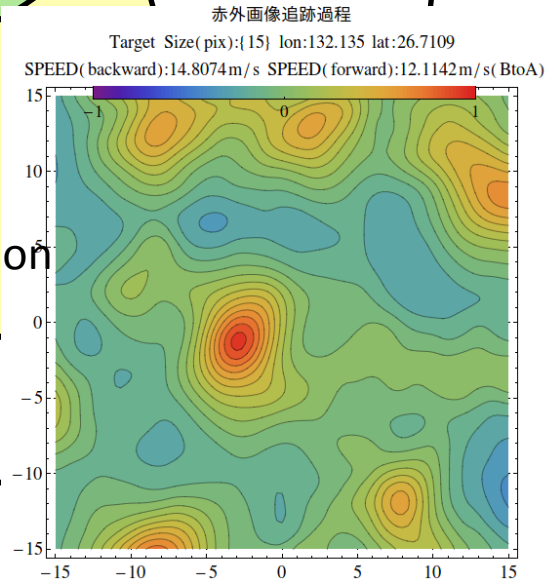
forward motion small scale

backward motion small scale

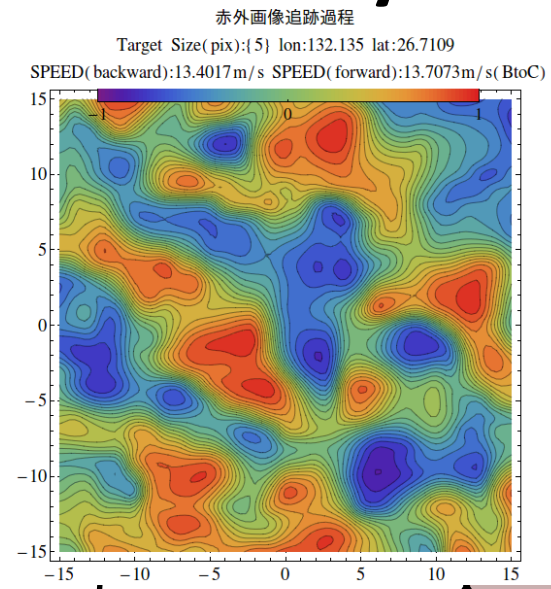


forward motion large scale

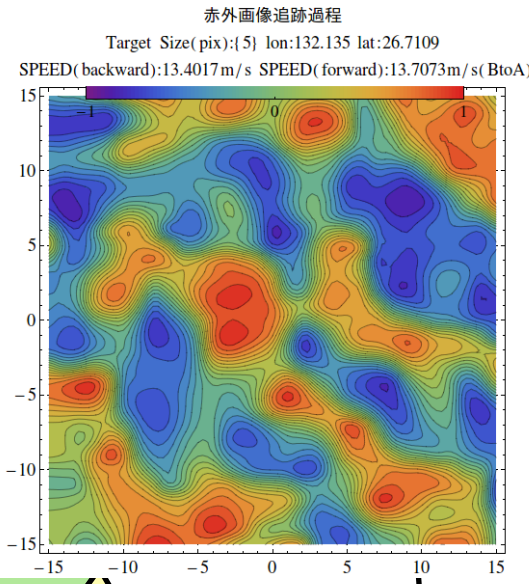
backward motion large scale



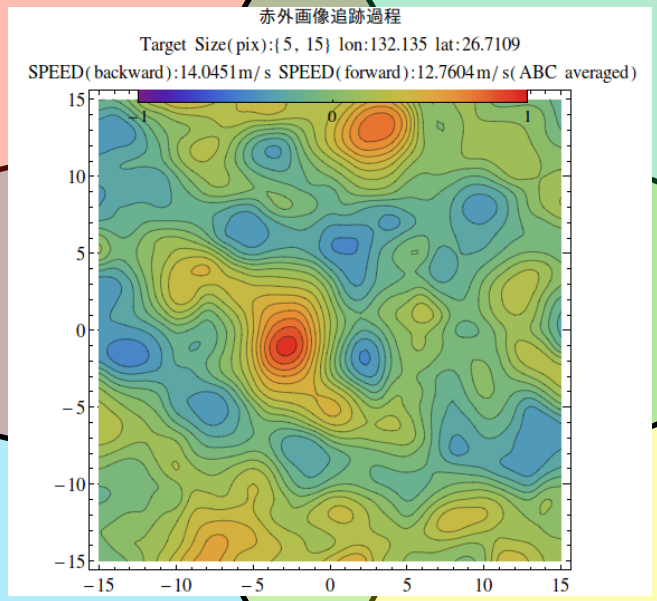
Likelihood estimation by temporal and spatial information

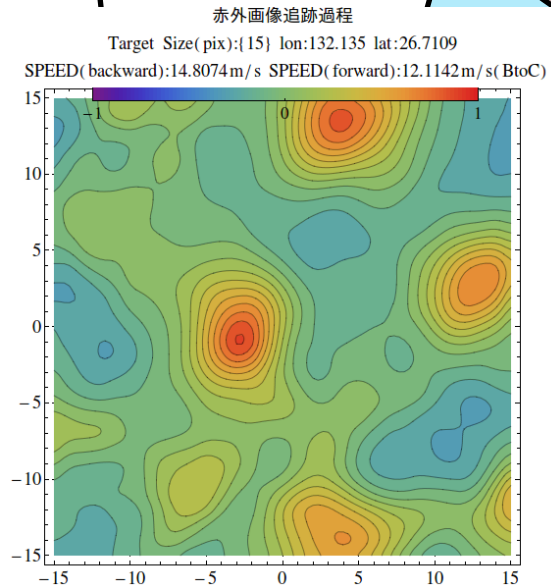


forward motion small scale



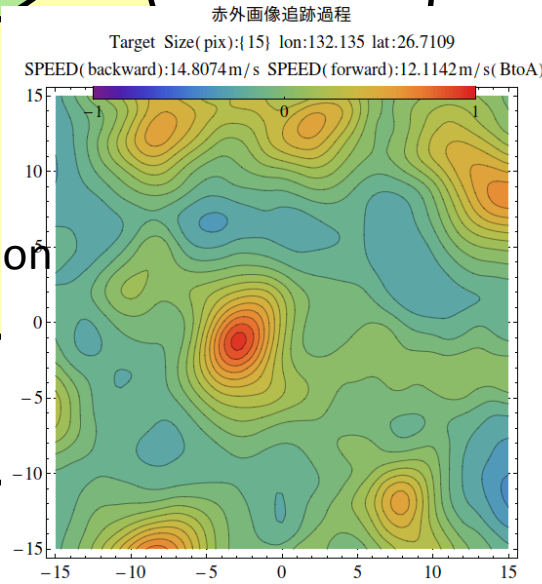
backward motion small scale





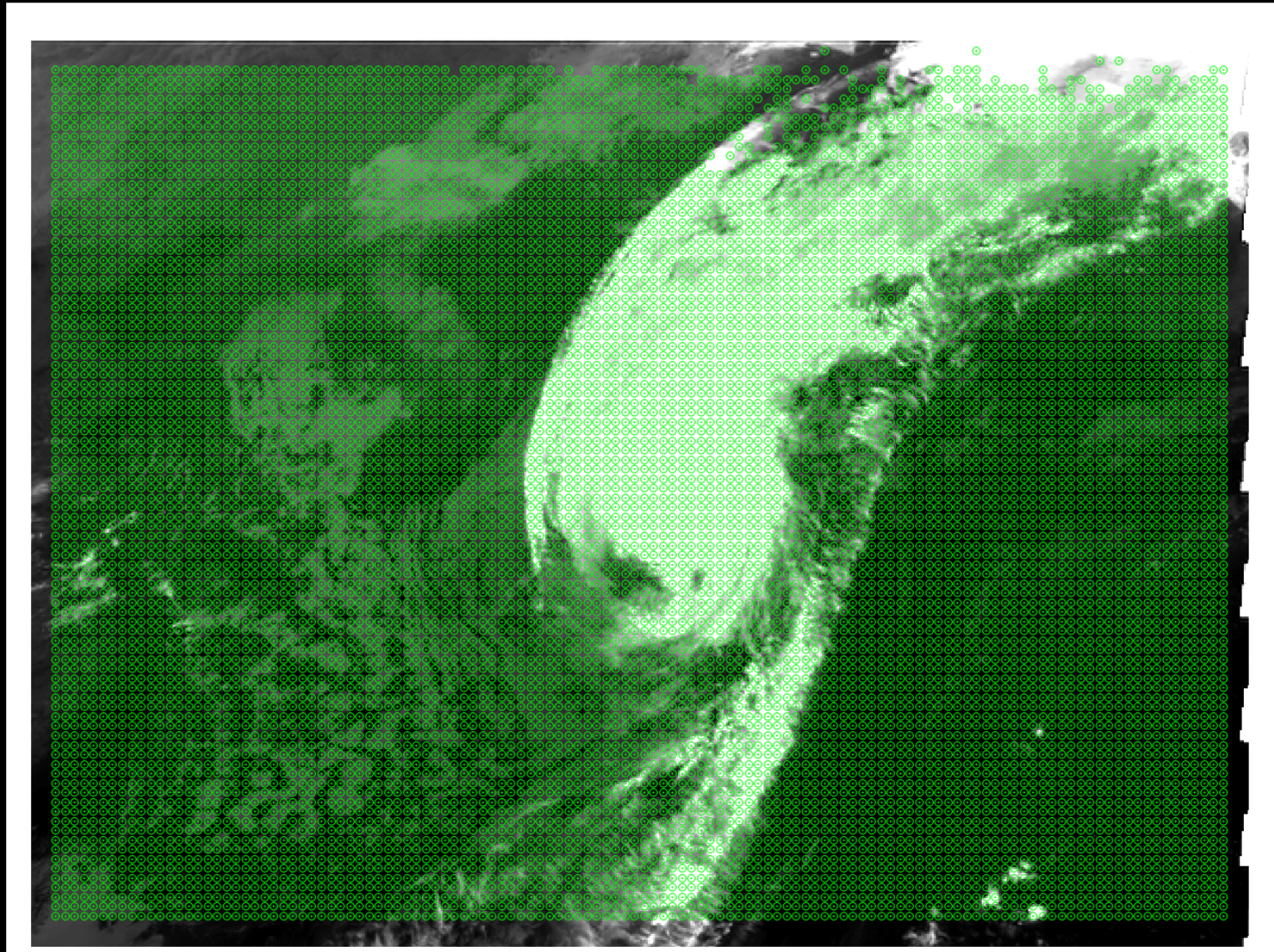
forward motion large scale

backward motion large scale



Target motion trajectories with small target box

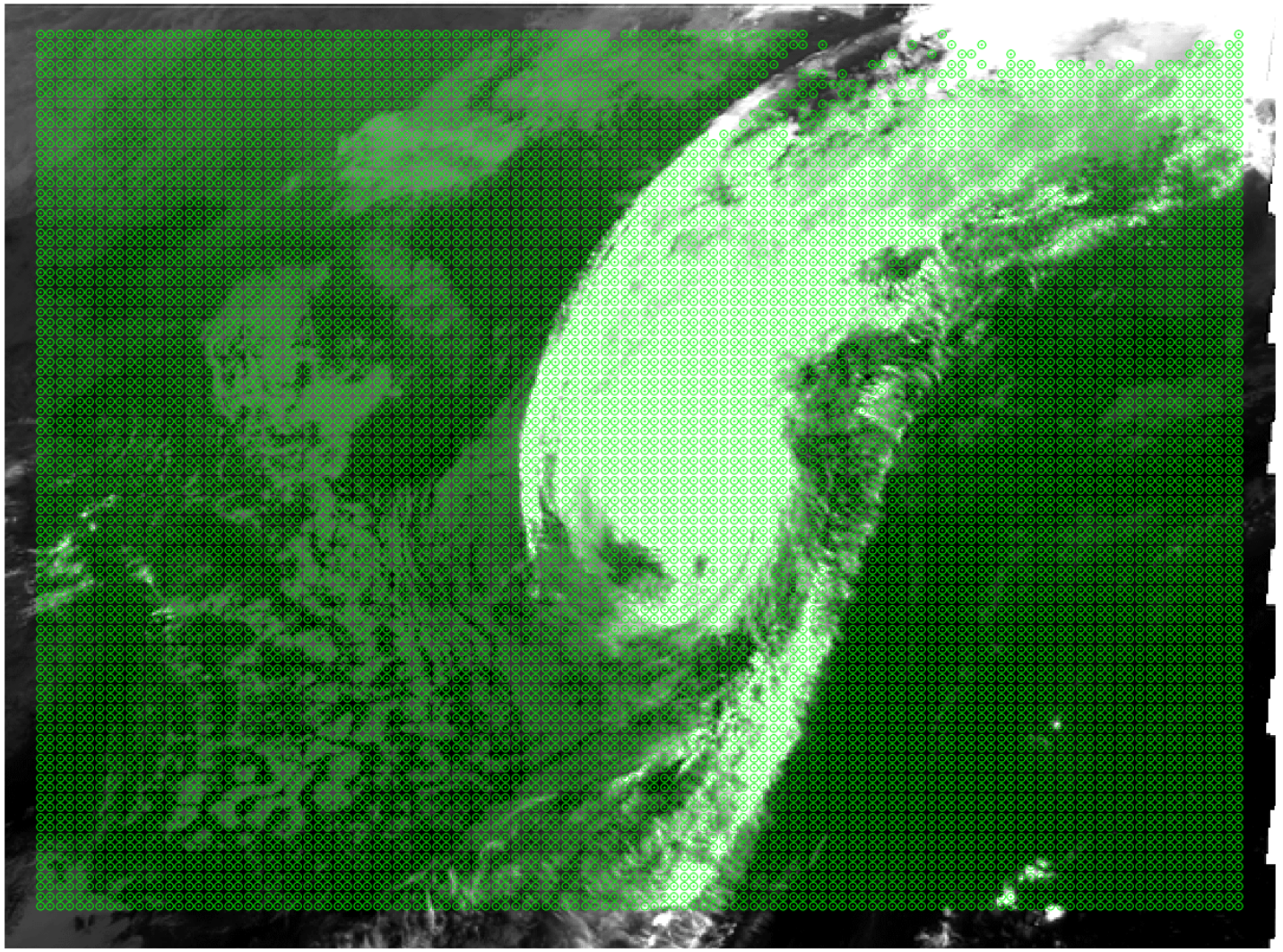
sat:MTSAT-1R
Channel:IR10.8
time interval:5min
target size:5x5pix
tracking: normal



Green: natural
Red: noisy track

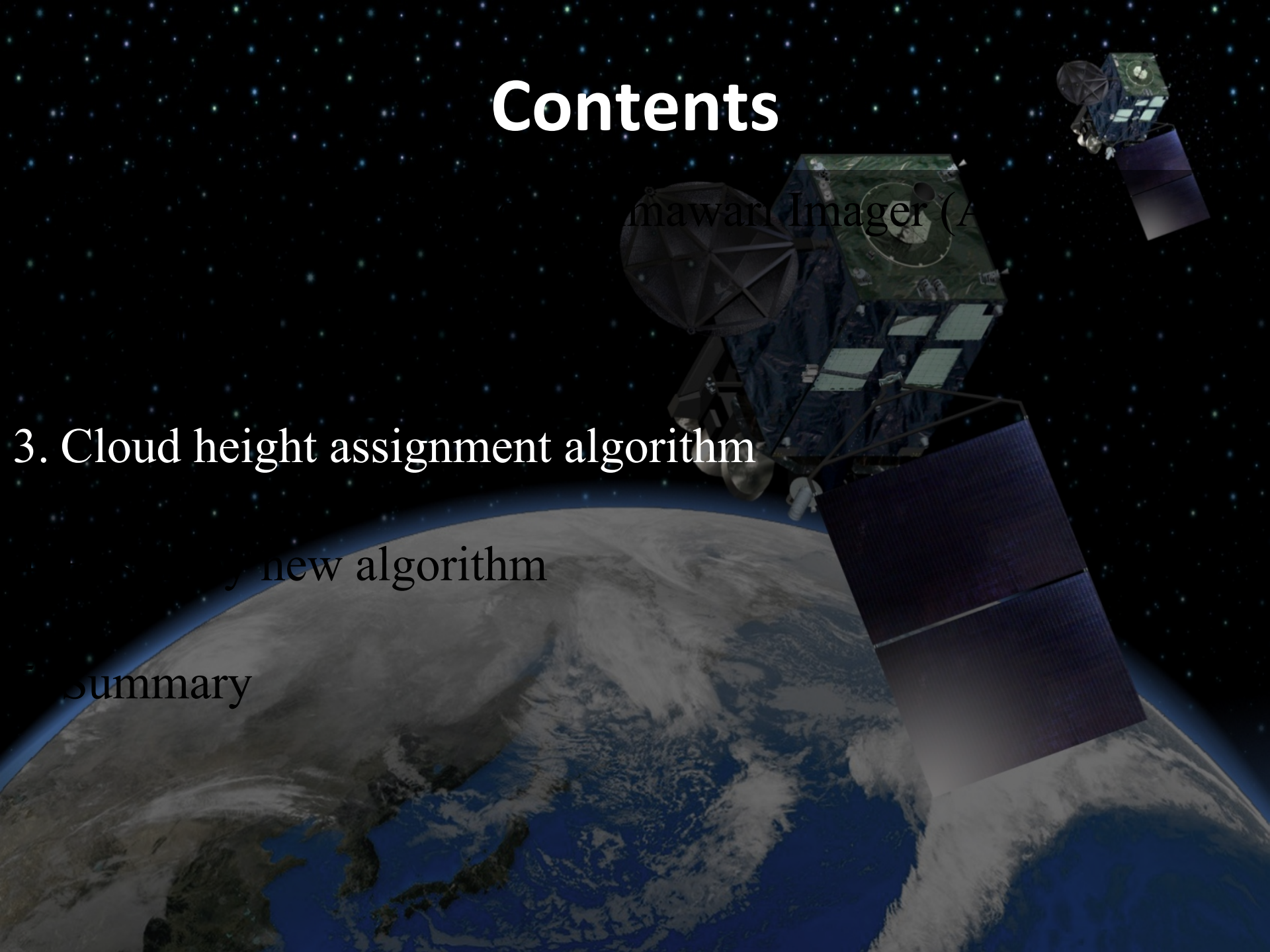
comparison to rapid scan tracking methods by checking cloud trajectory

sat:MTSAT-1R
Channel:IR10.8
time interval:
5min
target size:
5x5pix,15x15pix
tracking: time
and space MLE



Green: natural
Red: noisy track

Contents

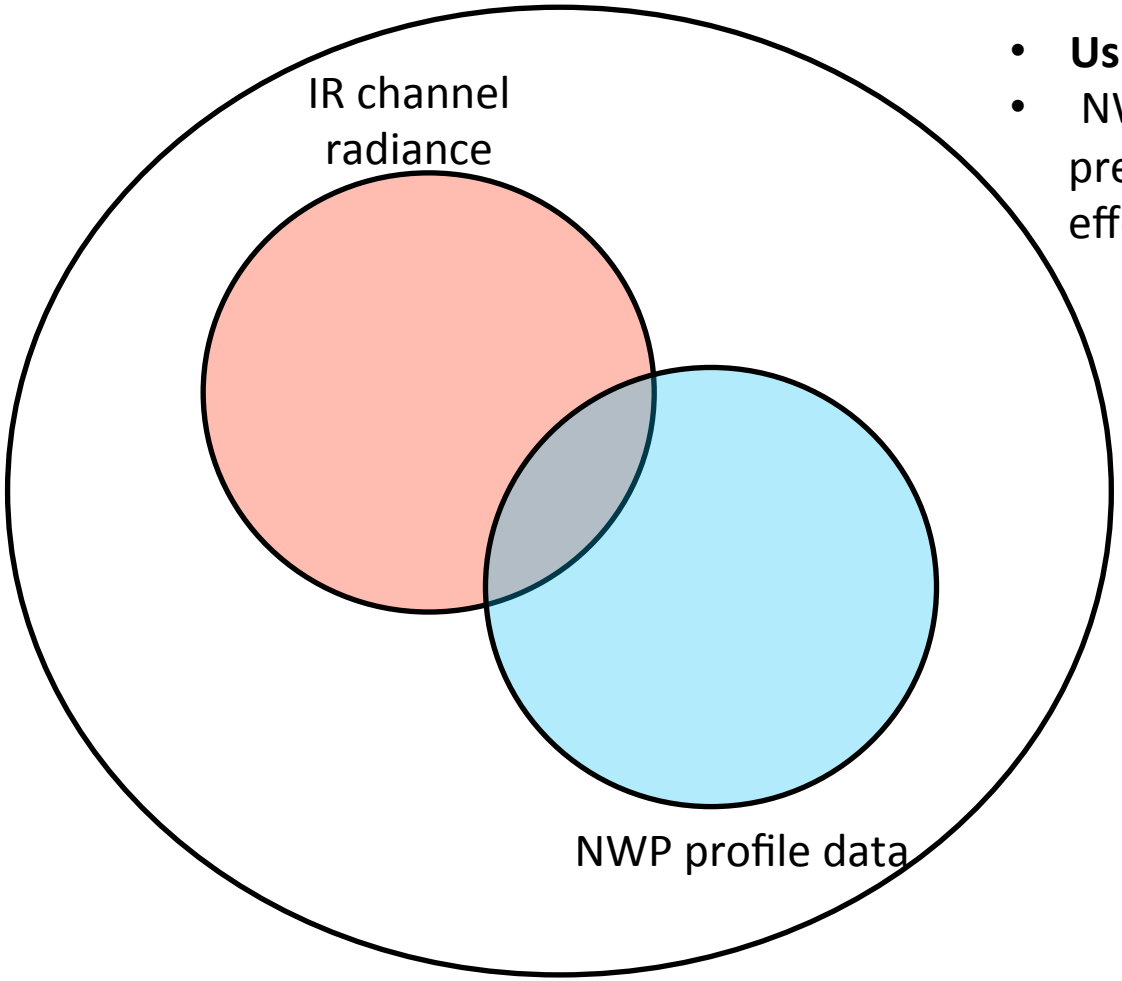


3. Cloud height assignment algorithm

new algorithm

Summary

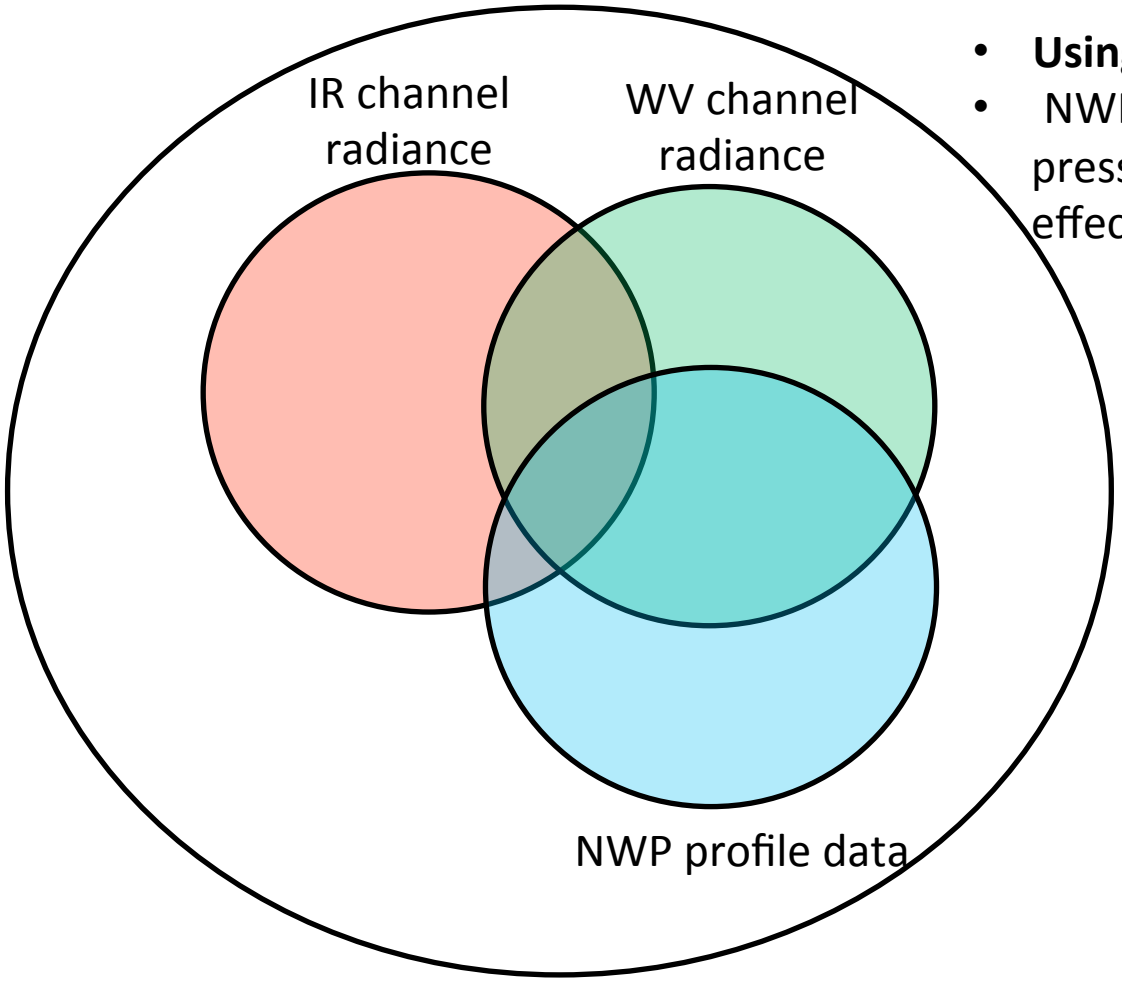
simultaneous use of radiance and motion vector for cloud height estimation



EBBT method

- **Using single band radiance information**
- NWP profile is needed for conversion to pressure and considering atmospheric effects to observed radiance

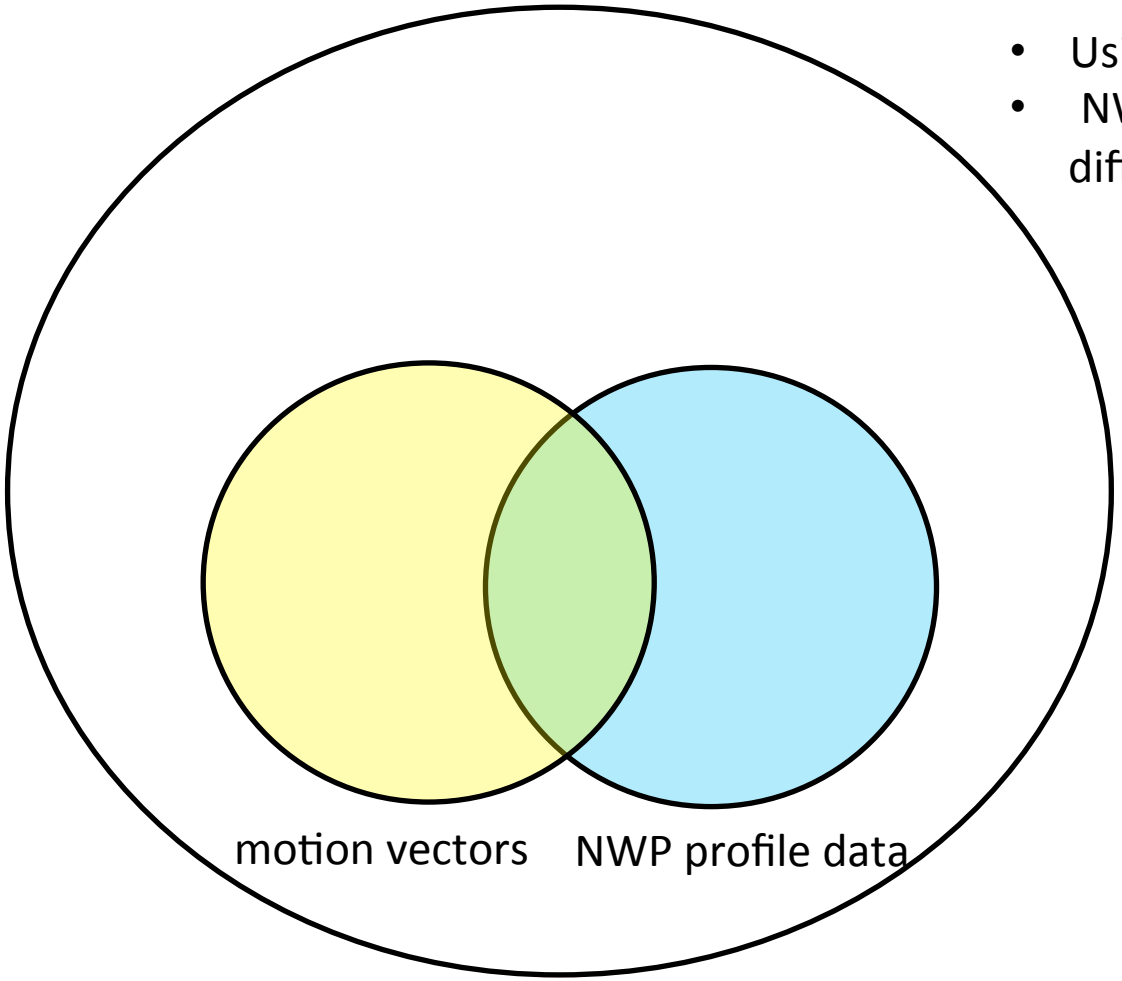
simultaneous use of radiance and motion vector for cloud height estimation



IR-WV intercept method

- **Using IR-WV bands radiance information**
- NWP profile is needed for conversion to pressure and considering atmospheric effects to observed radiance

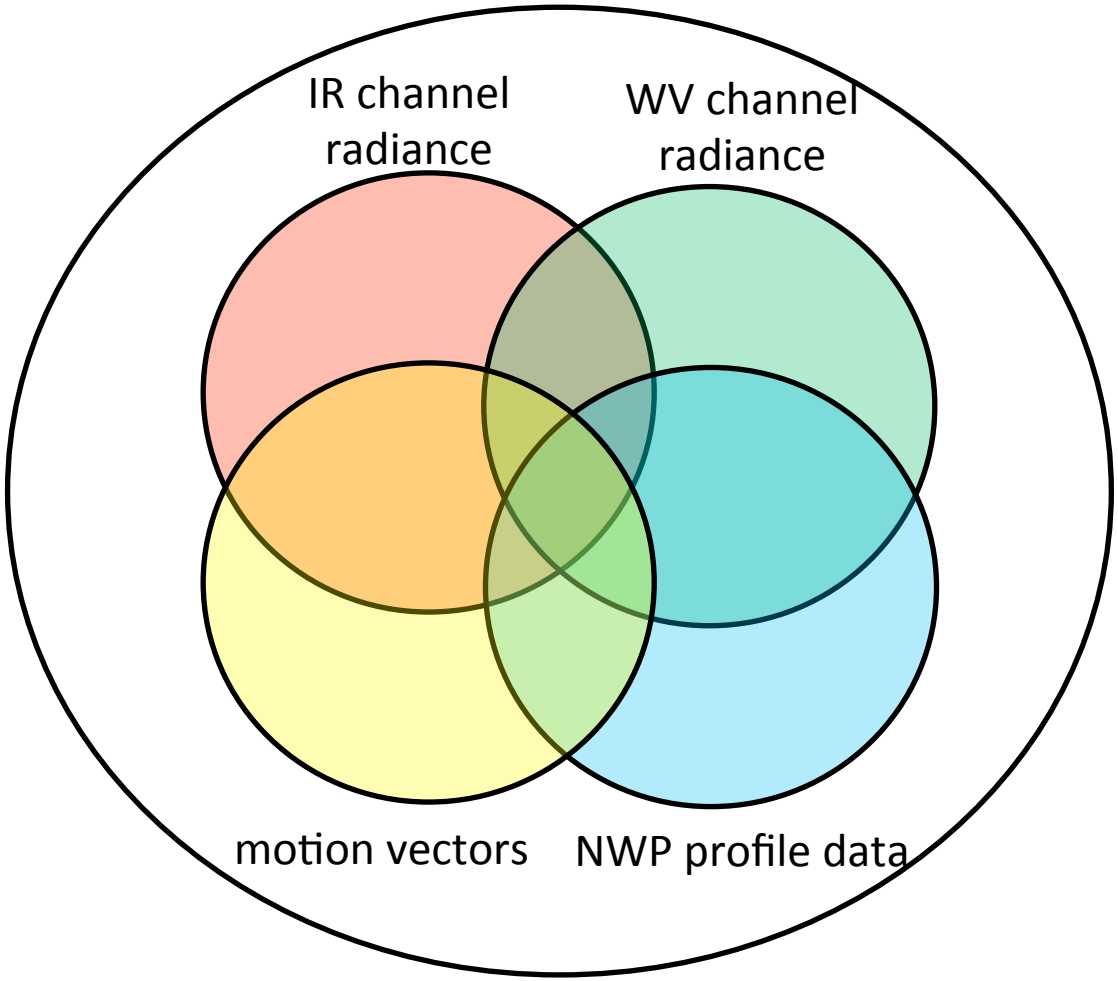
simultaneous use of radiance and motion vector for cloud height estimation



Best fit level method

- Using motion vector information
- NWP profile is needed for minimizing difference between AMV and NWP wind

simultaneous use of radiance and motion vector for cloud height estimation

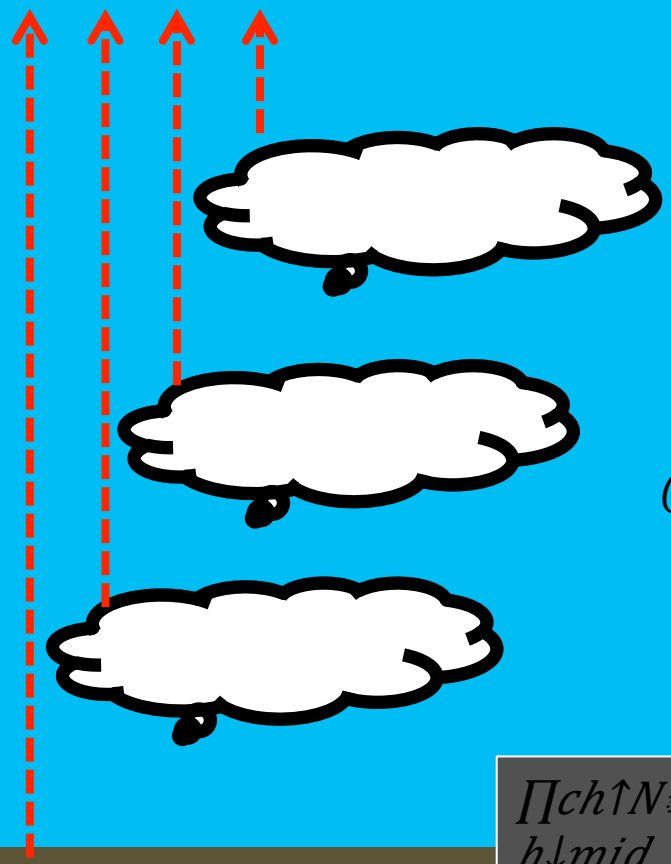


Maximum Likelihood Estimation for cloud height assignment

- Usable information for height assignment are radiance, motion vector and NWP profile data
- Likelihood function to be maximized must be defined (no convenient information such as correlation surface)
- Optimization algorithm required for searching optimal cloud height

Forward model

- Radiance rationing of from high, middle, low and ground layer
- 10.5, 12.0 and 6.7 micro meter imagery are used
- Averaged radiance in target box (5x5) is used

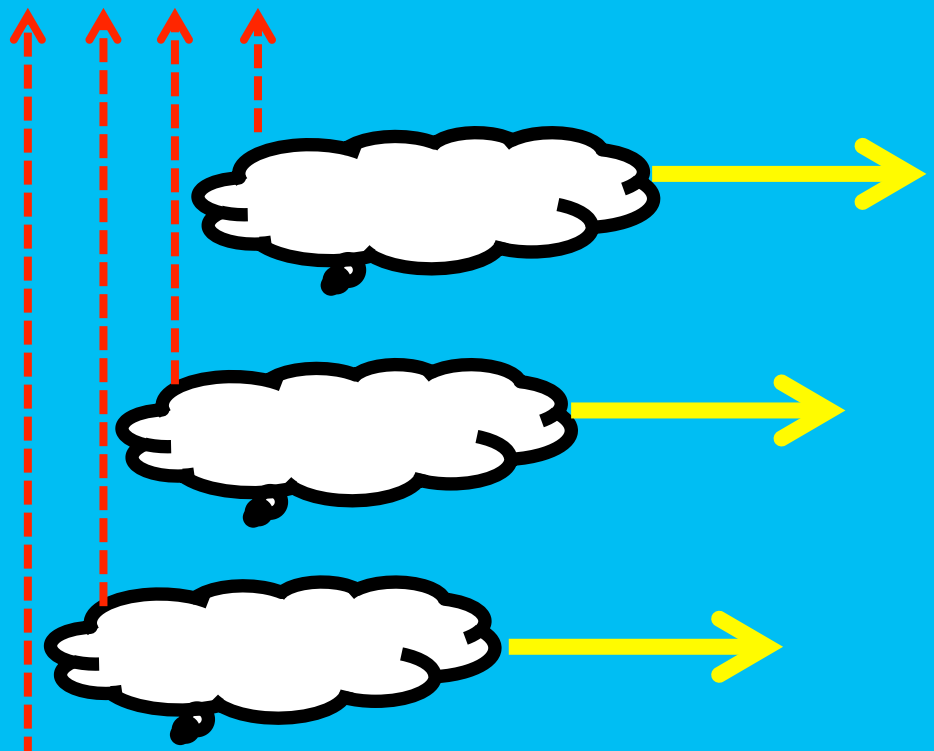


$$R(\rho\downarrow high, \rho\downarrow mid, \rho\downarrow low, h\downarrow high, h\downarrow mid, h\downarrow low) = \rho\downarrow high\ \varepsilon\downarrow high(ch)Rad(h\downarrow high) + \rho\downarrow mid\ \varepsilon\downarrow mid(ch)Rad(h\downarrow mid) + \rho\downarrow low\ \varepsilon\downarrow low(ch)Rad(h\downarrow low) + (1-(\rho\downarrow high+\rho\downarrow mid+\rho\downarrow low))\varepsilon\downarrow ground(ch)\mathrm{Rad}(\mathrm{ground})$$

$$\prod ch\uparrow N\ e\uparrow -(R\downarrow obs - R(\rho\downarrow high, \rho\downarrow mid, \rho\downarrow low, h\downarrow high, h\downarrow mid, h\downarrow low))\uparrow 2 /2\ \sigma\uparrow 2$$

usability of motion vectors for cloud height estimation

- wind vectors derived from VIS, IR and WV imagery are available
- Information of visible imagery is also available for height assignment by using VIS wind vector



$$v_{obs} = v_{nwp}\ (h_{high})$$

OR

$$v_{obs} = v_{nwp}\ (h_{mid})$$

OR

$$v_{obs} = v_{nwp}\ (h_{low})$$

$$\prod_{ch}^{N_{ch}} \left(1 - \prod_{layer}^{N_{layer}} \left(1 - e^{-\left(v_{obs} - v_{nwp}\ (h_{layer})\right)^2 / 2\sigma^2}\right)\right)$$

Optimization Strategy

- Not to minimize cost function but to maximize likelihood function which is set to 0-1 for handling not only “equation” but also “inequality” and fuzzy inference theory.

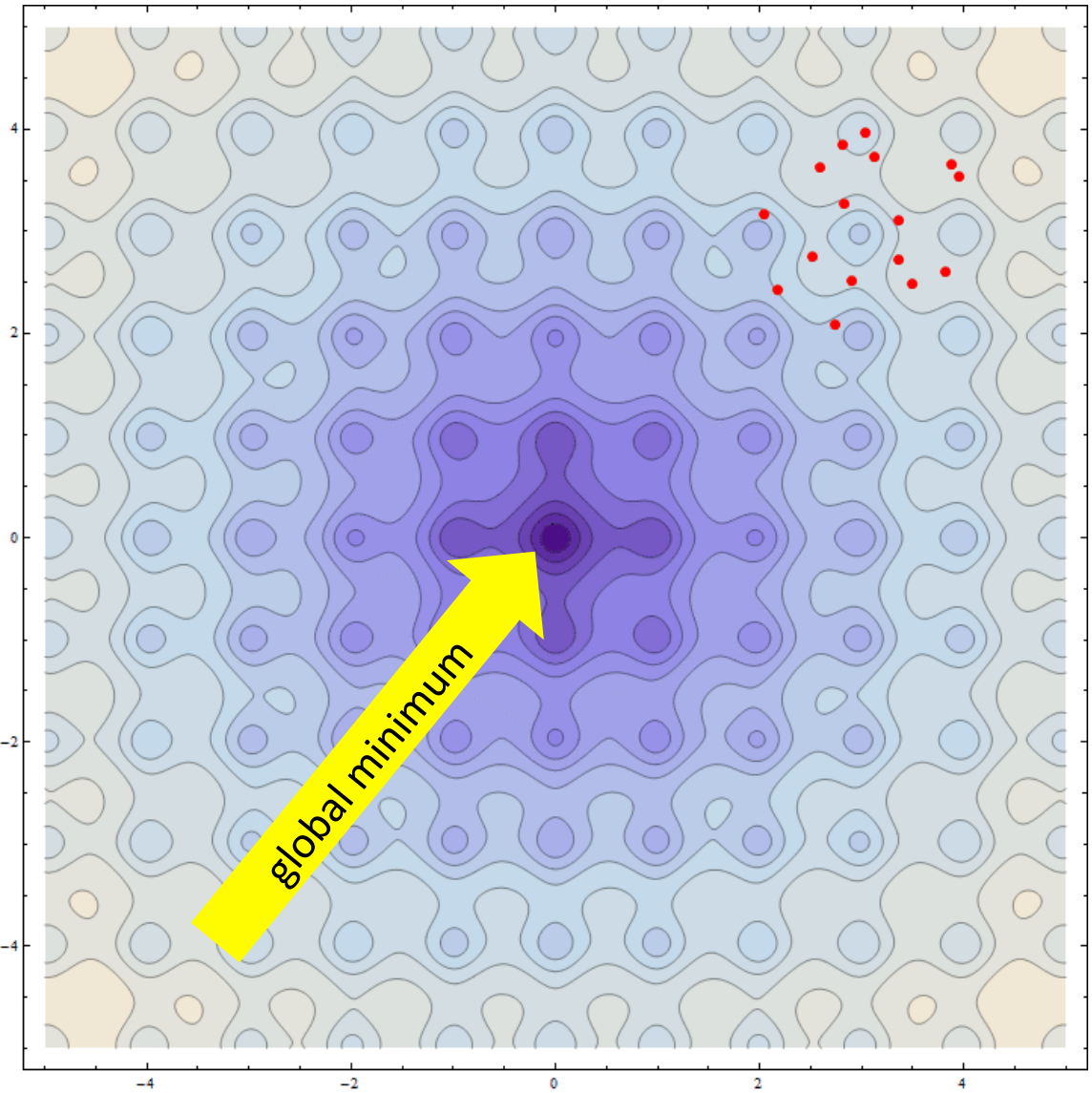
Likelihood function maximization
(available for simultaneous equation and inequality system and propositional logic)

Limit of cost function minimization (available for only simultaneous equation system)

.EQ.	$f(x)=y+\sigma$	$\rightarrow$	$L(f(x)=y+\sigma)= Exp(-(f(x)-y)^2/2\sigma^2)$
.AND.	$P \text{ and } Q$	$\rightarrow$	$L(P)\times L(Q)$
.GT.	$f(x)>y+\sigma$	$\rightarrow$	$L(f(x)>y+\sigma)= 1/2\,(1+Erf(f(x)-y/\sqrt{2}\,\sigma))$
.NOT.	$not\ P$		$\rightarrow 1-L(P)$
.OR.	$P \text{ or } Q = not(\ not(P) \text{ and } not(Q)\ )$		$\rightarrow 1-(1-L(P))(\ 1-L(Q))$
IF THEN	$if\ P\ then\ \ Q = not(\ P \text{ and } not(Q))$		$\rightarrow 1-L(P)(1-L(Q))$

In real computation, Cauchy distribution (and its CDF) used instead of normal distribution for searching optimal latent variables

Optimization method - Differential Evolution method



Test function : Ackley's function

$$f(x,y) = -20\exp\left(-0.2\sqrt{0.5\left(x^2+y^2\right)}\right) - \exp\left(0.5\left(\cos\left(2\pi x\right)+\cos\left(2\pi y\right)\right)\right) + 20 + e.$$

Too many local minima
⇒difficult to find optimal parameter by methods using derivative function

initial points are changed by iteration of

1. **mutation evolution**
2. **crossover**
3. **survival of the fit**

operations .

Storn, R.; Price, K. (1997). "Differential evolution - a simple and efficient heuristic for global optimization over continuous spaces". *Journal of Global Optimization* **11**: 341–359

Contents

4. Result by new algorithm

5. Summary

AMV derivation experiment using new tracking and HA technique

Satellite : MTSAT-2

Period : January 2013 (winter)

RTN

Target selection : MTSAT operational method

Tracking : Cross-Correlation

Height assign : operational method

TEST1

Target selection : MTSAT operational method

Tracking : Cross-Correlation, MLE using 5x5 and 15x15 pixels

Height assign : MLE height estimation using only radiance information

TEST2

Target selection : MTSAT operational method

Tracking : Cross-Correlation, MLE using 5x5 and 15x15 pixels

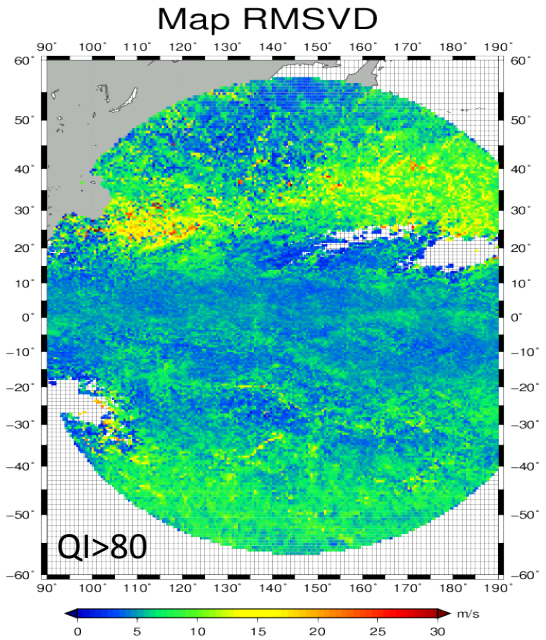
Height assign : MLE height estimation using radiance and tracked motion

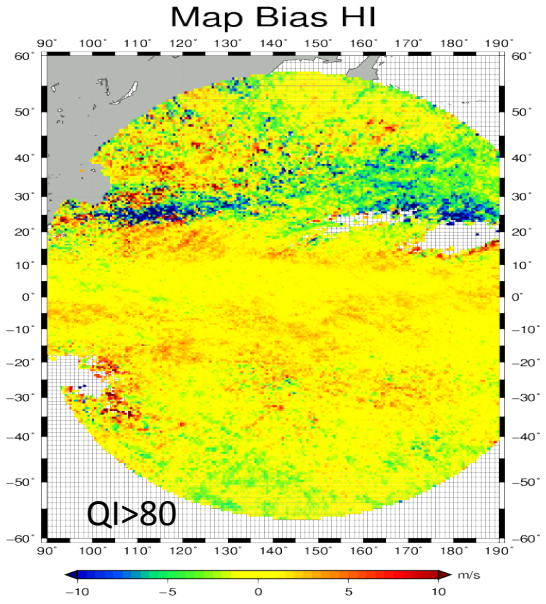
Temporal information for tracking is not used in this experiment

- **for simplifying comparison using QI (consistent vector shows high quality even case that temporal QI is low)**

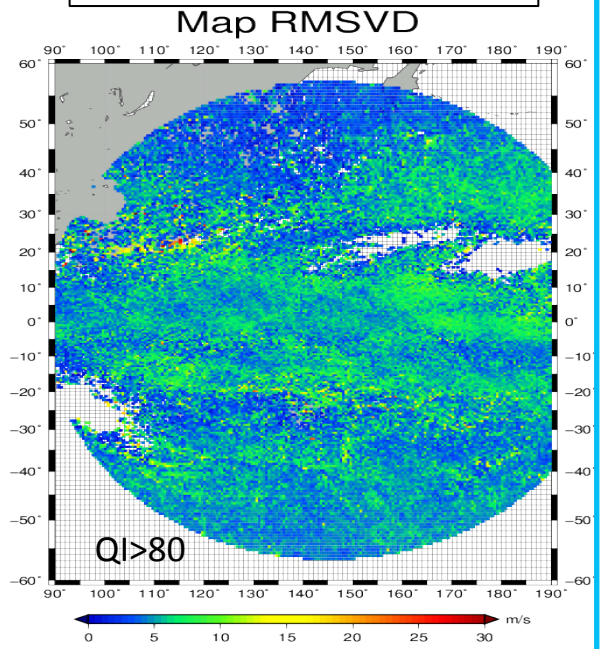
IR upper level AMV O-B statistic for January 2013

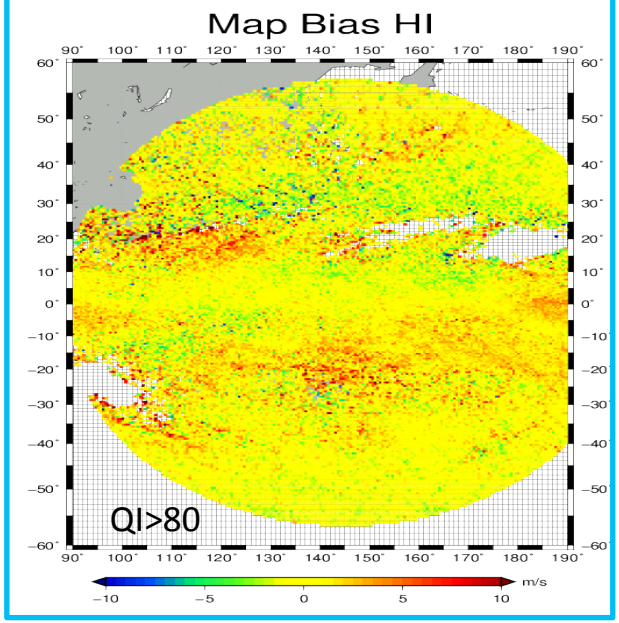
operation



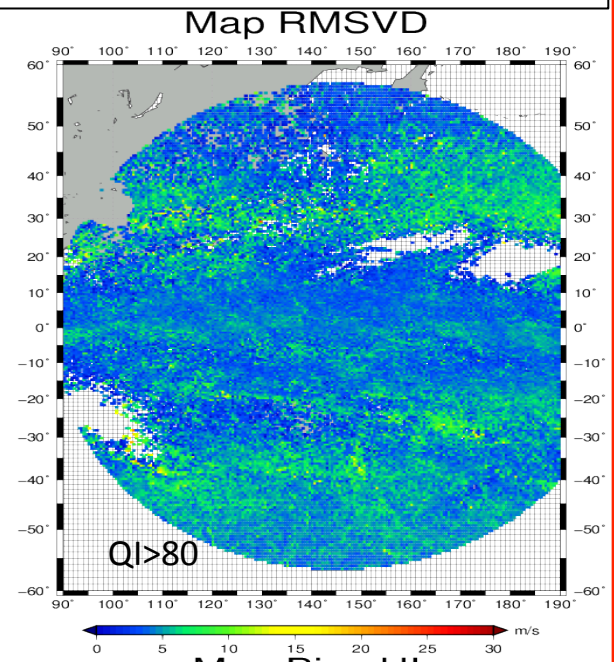


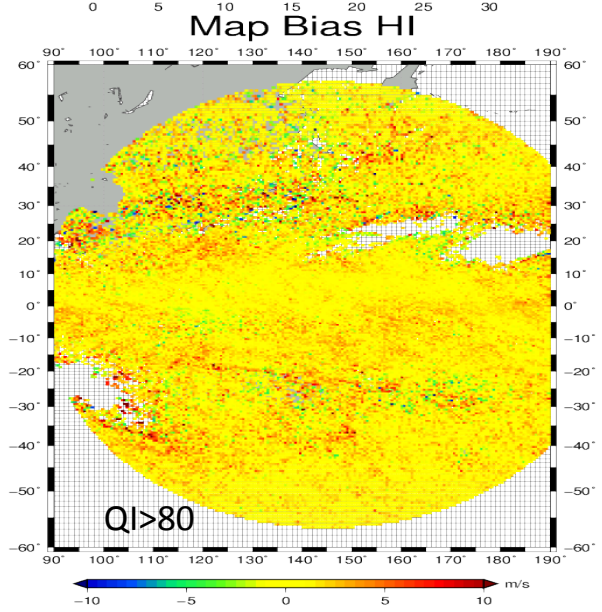
TEST1 : radiance only





TEST2 : radiance and motion





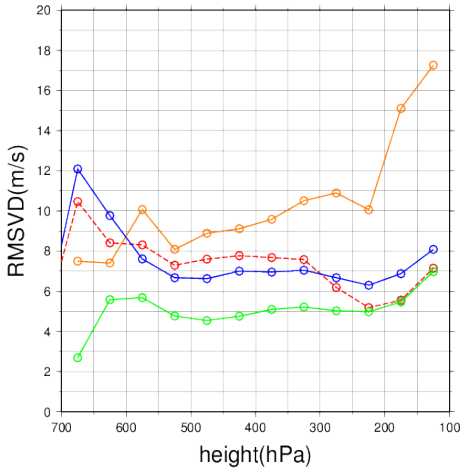
IR upper level AMV O-B statistic for January 2013

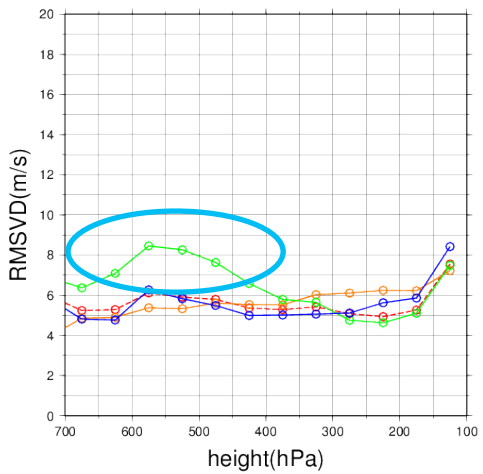
TEST1 : radiance only

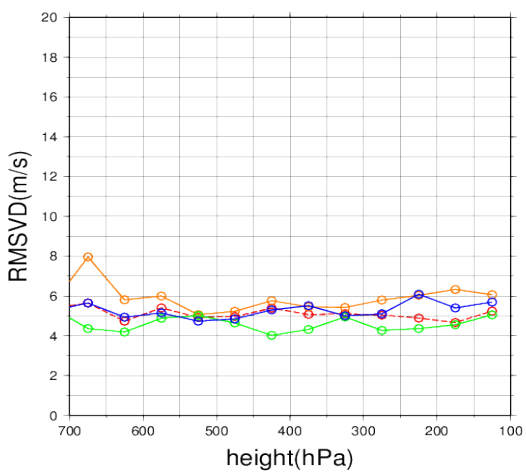
TEST2 : radiance and motion

Full Disk
NH
TROP
SH

RMSVD Histogram HI





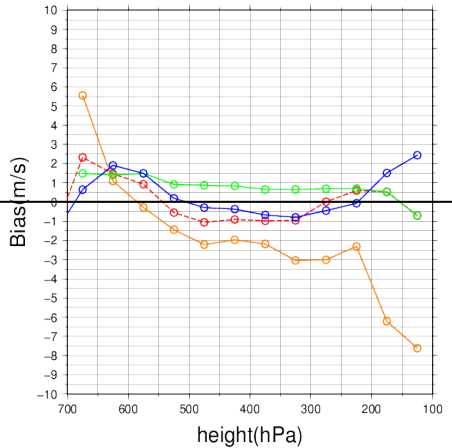


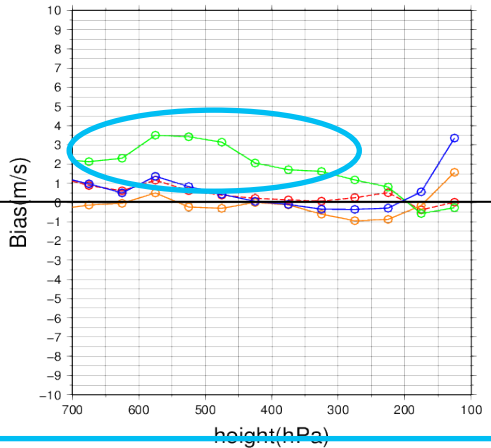
QI>80

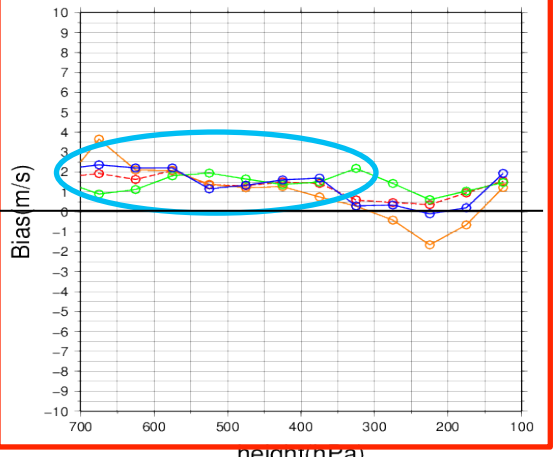
QI>80

QI>80

Bias Histogram HI







0 m/s

IR upper level AMV sonde statistics for January 2013

Only radiance information used

RTN

HIGH LEVEL

	FULL DISK	NH	TROP	SH
MVD	4.81	7.22	4.45	5.48
RMSVD	5.79	8.65	5.23	6.63
BIAS	−0.7	0.31	−0.94	0.71
SPD	15.09	35.40	11.78	23.73

MEDIUM LEVEL

	FULL DISK	NH	TROP	SH
MVD	6.17	6.57	3.93	5.28
RMSVD	7.74	8.23	4.54	6.04
BIAS	−1.67	−2.08	0.01	−0.01
SPD	21.38	23.14	9.43	19.65

TEST1

	FULL DISK	NH	TROP	SH
MVD	5.88	6.34	5.77	5.91
RMSVD	7.15	7.57	7.06	6.99
BIAS	−1.34	−1.20	−1.53	0.31
SPD	18.31	36.90	13.27	25.84

	FULL DISK	NH	TROP	SH
MVD	5.28	5.50	3.76	5.27
RMSVD	6.4	6.67	4.21	6.20
BIAS	−0.69	−0.85	−0.17	0.29
SPD	22.02	23.94	9.74	19.84

Method : Comparison of rawinsonde winds with AMV winds within 150 km radius of a RAOB site

Filters : VERT. DIST.(>=700hPa) < 50 (hPa)
VERT. DIST.(<700hPa) < 35 (hPa)
QUALITY >= 85
0.5*0.5 deg. latitude/longitude grid point data
SPEED DIFF. < 30 (m/s) - DIRECTION DIFF. < 90 (deg)

IR upper level AMV sonde statistics for January 2013

Both of radiance and motion vector information used

RTN

HIGH LEVEL

	FULL DISK	NH	TROP	SH
MVD	4.81	7.22	4.45	5.48
RMSVD	5.79	8.65	5.23	6.63
BIAS	−0.7	0.31	−0.94	0.71
SPD	15.09	35.40	11.78	23.73

MEDIUM LEVEL

	FULL DISK	NH	TROP	SH
MVD	6.17	6.57	3.93	5.28
RMSVD	7.74	8.23	4.54	6.04
BIAS	−1.67	−2.08	0.01	−0.01
SPD	21.38	23.14	9.43	19.65

TEST2

	FULL DISK	NH	TROP	SH
MVD	5.04	6.51	4.63	5.96
RMSVD	6.03	7.79	5.45	6.98
BIAS	−0.34	−1.04	−0.21	0.04
SPD	19.26	37.21	14.42	27.57

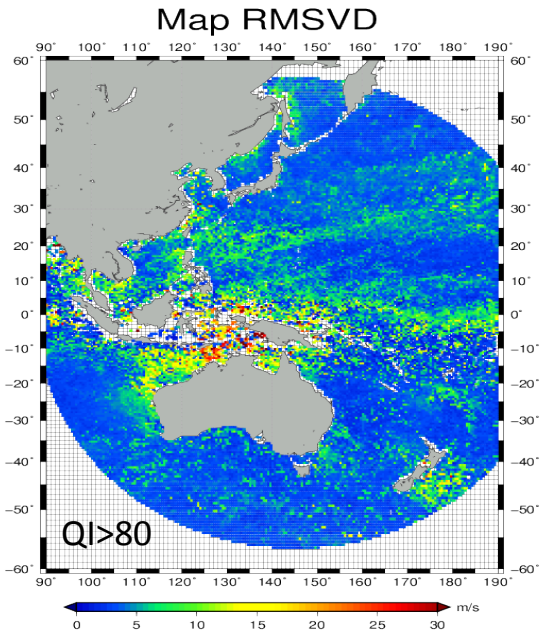
	FULL DISK	NH	TROP	SH
MVD	5.06	5.29	3.89	6.14
RMSVD	6.05	6.30	4.53	7.13
BIAS	0.85	1.06	−0.59	2.88
SPD	21.16	23.82	10.11	25.78

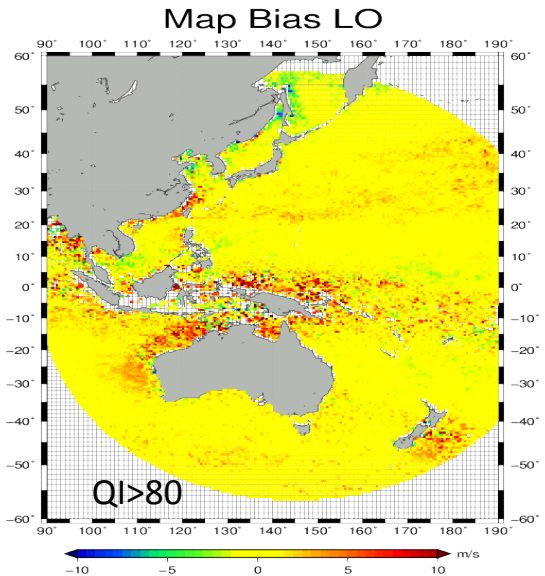
Method : Comparison of rawinsonde winds with AMV winds within 150 km radius of a RAOB site

Filters : VERT. DIST.(>=700hPa) < 50 (hPa)
VERT. DIST.(<700hPa) < 35 (hPa)
QUALITY >= 85
0.5*0.5 deg. latitude/longitude grid point data
SPEED DIFF. < 30 (m/s) - DIRECTION DIFF. < 90 (deg)

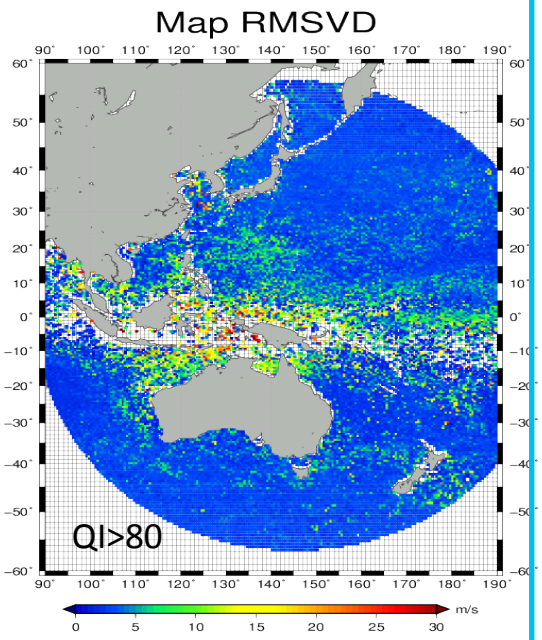
IR lower level AMV O-B statistic for January 2013

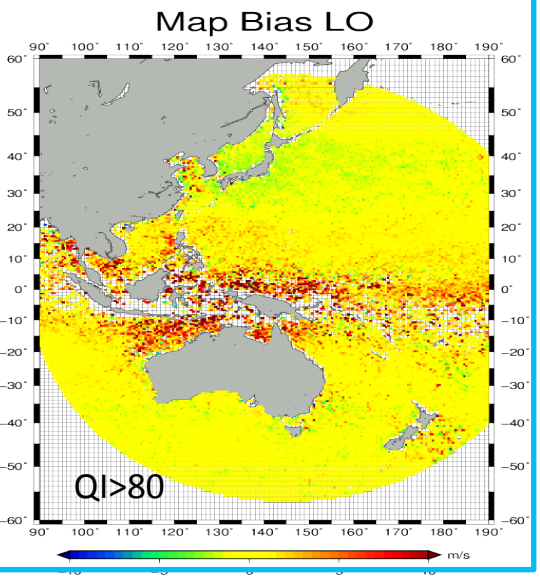
operation



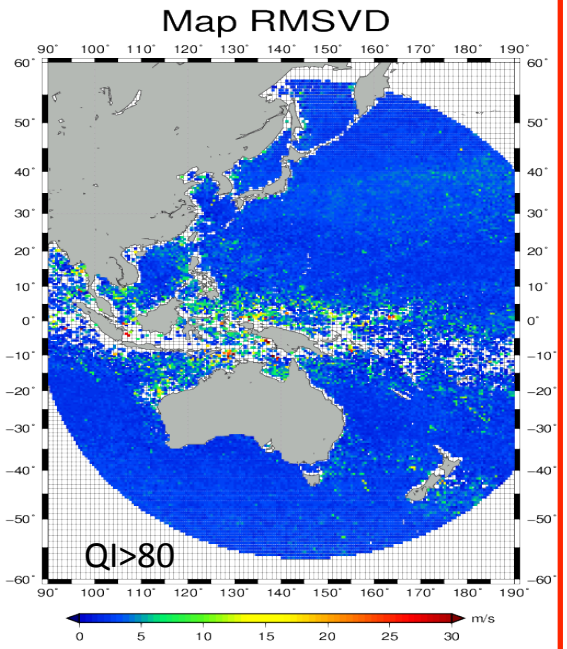


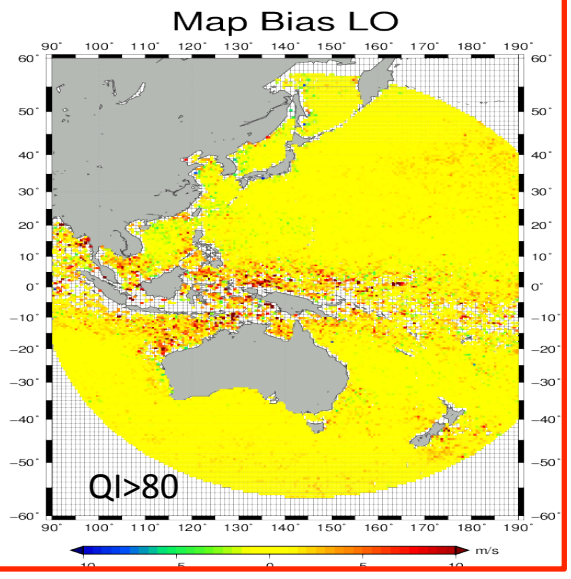
TEST1 : radiance only





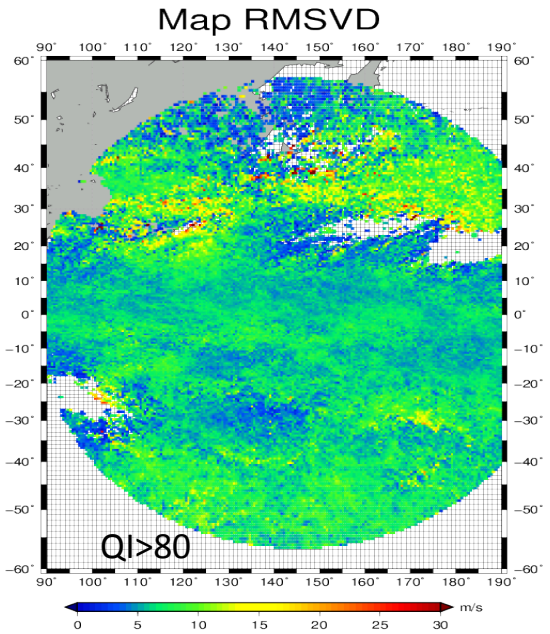
TEST2 : radiance and motion

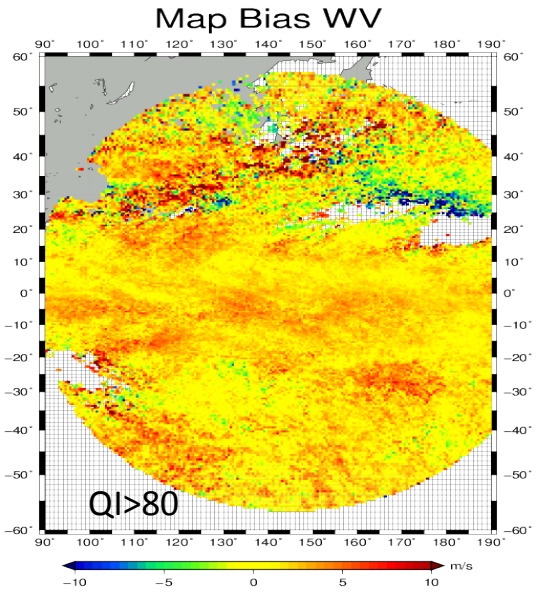




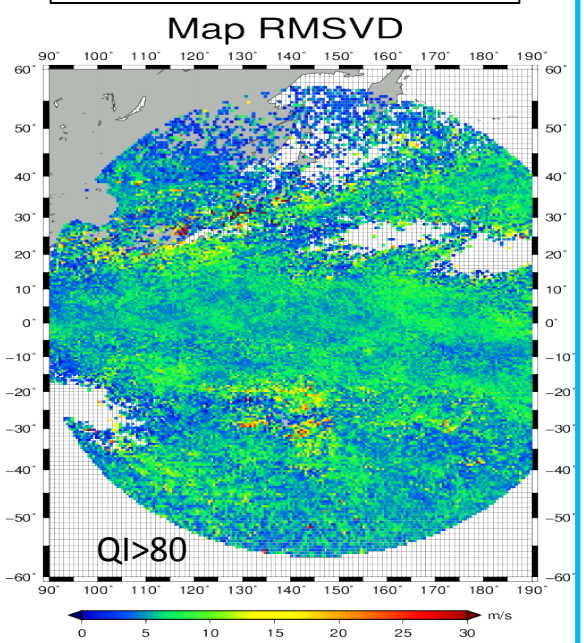
WV cloudy AMV O-B statistic for January 2013

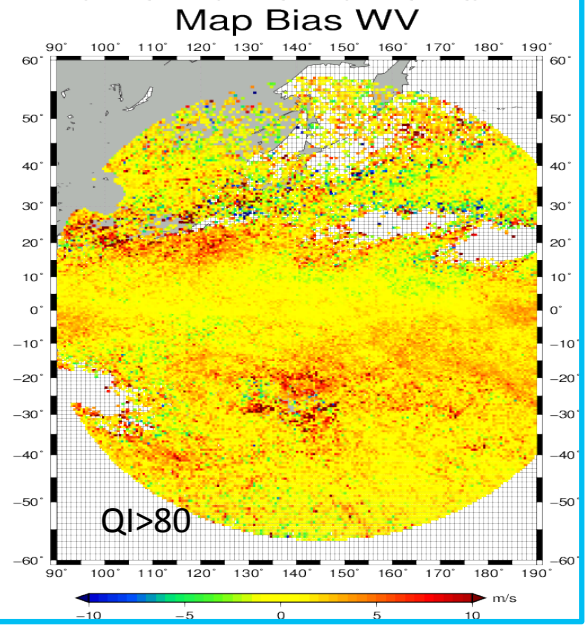
operation



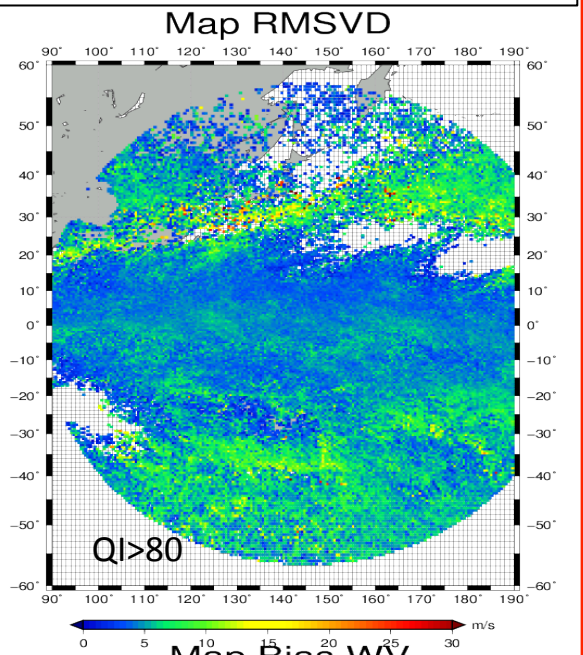


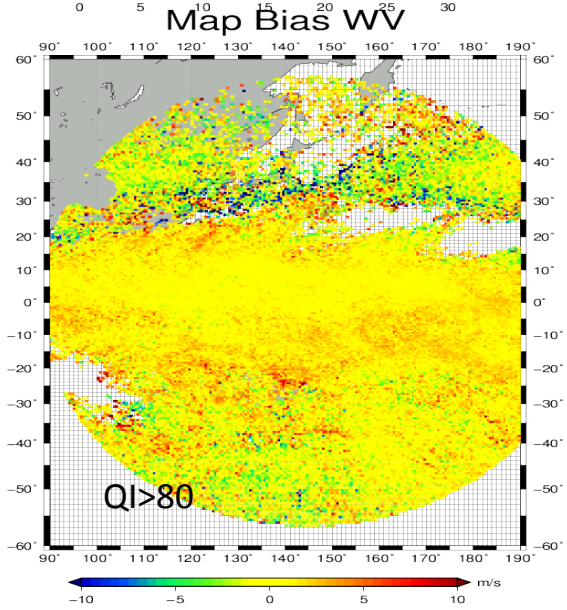
TEST1 : radiance only





TEST2 : radiance and motion





Summary

- By deriving motion vectors from sum of four correlation surfaces derived from small, large target boxes, and from forward and backward matching, Tracking accuracy was improved.

- BIAS and RMSVD of MTSAT IR AMV are totally improved by proposal height assignment method in case to use only radiance information. But as for BIAS, quality debased over tropical region.

- As a result to use motion vector as auxiliary information for height assignment, error and its homogeneity are improved, but positive BIAS can be seen in southern hemisphere.