Development of DSM Detection with airborne/spaceborne SAR data

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Introduction：

This presentation is based on author’s researches in 1998 to 2000. The researches were concerned to ways of developing DSM (Digital Surface Model) using airborne and spaceborne SAR (Synthetic Aperture Radar) data. This presentation introduces those studies.

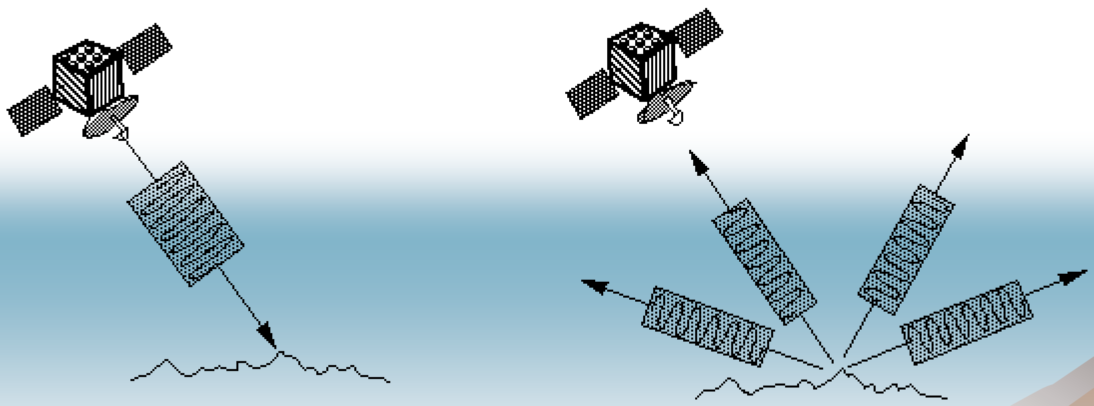
*As elevation models that were detected with X-Band or C-Band SAR data corresponded not with earth’s surface but the top of trees or buildings, so the models that are mentioned in this presentation, are DSMs.

0）What‘s SAR（Synthetic Aperture Radar）

1: **Explanation of Imaging Radar**

A typical radar (RAdio Detection and Ranging) measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths (in the range 1 cm to 1 m, which corresponds to a frequency range of about 300 MHz to 30 GHz) and polarizations (waves polarized in a single vertical or horizontal plane).

The energy in the radar pulse is scattered in all directions, with some reflected back toward the antenna. This backscatter returns to the radar as a weaker radar echo and is received by the antenna in a specific polarization. These echoes are converted to digital data and passed to a data recorder for later processing and display as an image. Given that the radar pulse travels at the speed of light, it is relatively straightforward to use the measured time for the roundtrip of a particular pulse to calculate the distance or range to the reflecting object. The chosen pulse bandwidth determines the resolution in the range (cross-track) direction.



Radar transmits a pulse Measures reflected echo (backscatter)

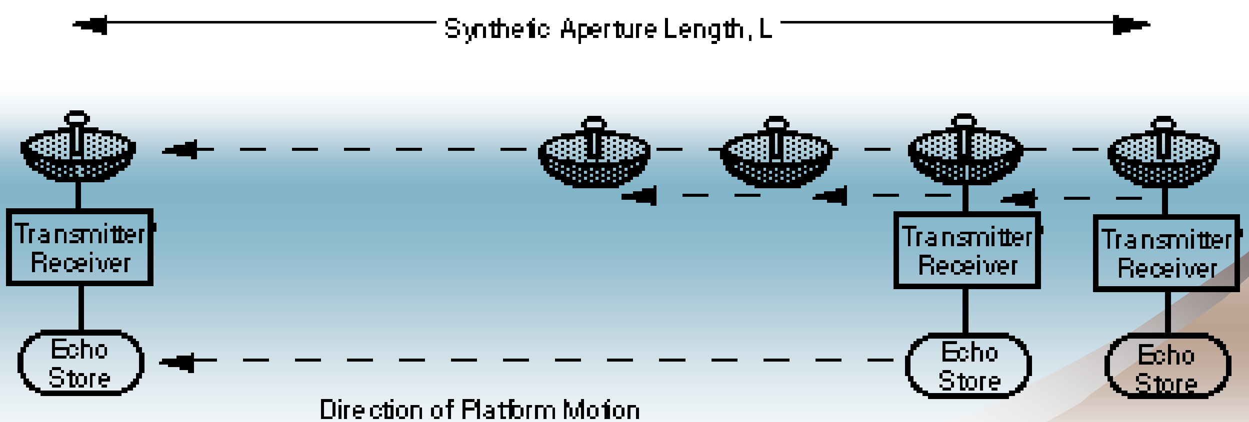
From JPL/NASA Homepage http://www.jpl.nasa.gov/

0）What‘s SAR（Synthetic Aperture Radar）

2: Constructing “Synthetic Aperture”

The length of the radar antenna determines the resolution in the azimuth (along-track) direction of the image: the longer the antenna, the finer the resolution in this dimension. *Synthetic Aperture Radar (SAR)* refers to a technique used to synthesize a very long antenna by combining signals (echoes) received by the radar as it moves along its flight track. Aperture means the opening used to collect the reflected energy that is used to form an image. In the case of a camera, this would be the shutter opening; for radar it is the antenna. A *synthetic* aperture is constructed by moving a real aperture or antenna through a series of positions along the flight track.

As the radar moves, a pulse is transmitted at each position; the return echoes pass through the receiver and are recorded in an 'echo store.' Because the radar is moving relative to the ground, the returned echoes are Doppler-shifted. Comparing the Doppler-shifted frequencies to a reference frequency allows many returned signals to be "focused" on a single point, effectively increasing the length of the antenna that is imaging that particular point. The trick in SAR processing is to correctly match the variation in Doppler frequency for each point in the image: this requires very precise knowledge of the relative motion between the platform and the imaged objects.



From JPL/NASA Homepage http://www.jpl.nasa.gov/

0）What‘s SAR（Synthetic Aperture Radar）

3: Radar Image

Synthetic aperture radar is now a mature technique used to generate radar images in which fine detail can be resolved. SARs provide unique capabilities as an imaging tool. Because they provide their own illumination (the radar pulses), they can image at any time of day or night, regardless of sun illumination. And because the radar wavelengths are much longer than those of visible or infrared light, SARs can also "see" through cloudy and dusty conditions that visible and infrared instruments cannot.

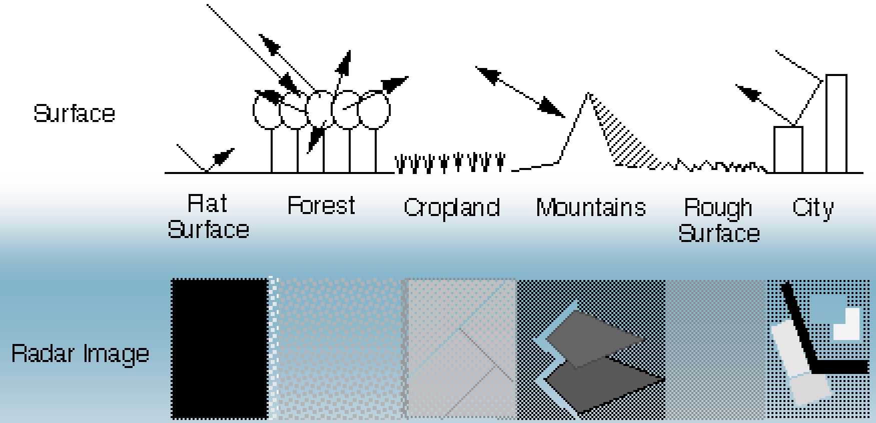
Radar images are composed of many dots, or picture elements. Each pixel (picture element) in the radar image represents the radar backscatter for that area on the ground: darker areas in the image represent low backscatter, brighter areas represent high backscatter. Bright features mean that a large fraction of the radar energy was reflected back to the radar, while dark features imply that very little energy was reflected. Backscatter for a target area at a particular wavelength will vary for a variety of conditions: size of the scatterers in the target area, moisture content of the target area, polarization of the pulses, and observation angles. Backscatter will also differ when different wavelengths are used.

From JPL/NASA Homepage http://www.jpl.nasa.gov/

0)What‘s SAR(Synthetic Aperture Radar)

3: Radar Image

A useful rule-of-thumb in analyzing radar images is that the higher or brighter the backscatter on the image, the rougher the surface being imaged. Flat surfaces that reflect little or no microwave energy back towards the radar will always appear dark in radar images. Vegetation is usually moderately rough on the scale of most radar wavelengths and appears as grey or light grey in a radar image. Surfaces inclined towards the radar will have a stronger backscatter than surfaces which slope away from the radar and will tend to appear brighter in a radar image. Some areas not illuminated by the radar, like the back slope of mountains, are in shadow, and will appear dark. When city streets or buildings are lined up in such a way that the incoming radar pulses are able to bounce off the streets and then bounce again off the buildings (called a double- bounce) and directly back towards the radar they appear very bright (white) in radar images. Roads and freeways are flat surfaces so appear dark. Buildings which do not line up so that the radar pulses are reflected straight back will appear light grey, like very rough surfaces.



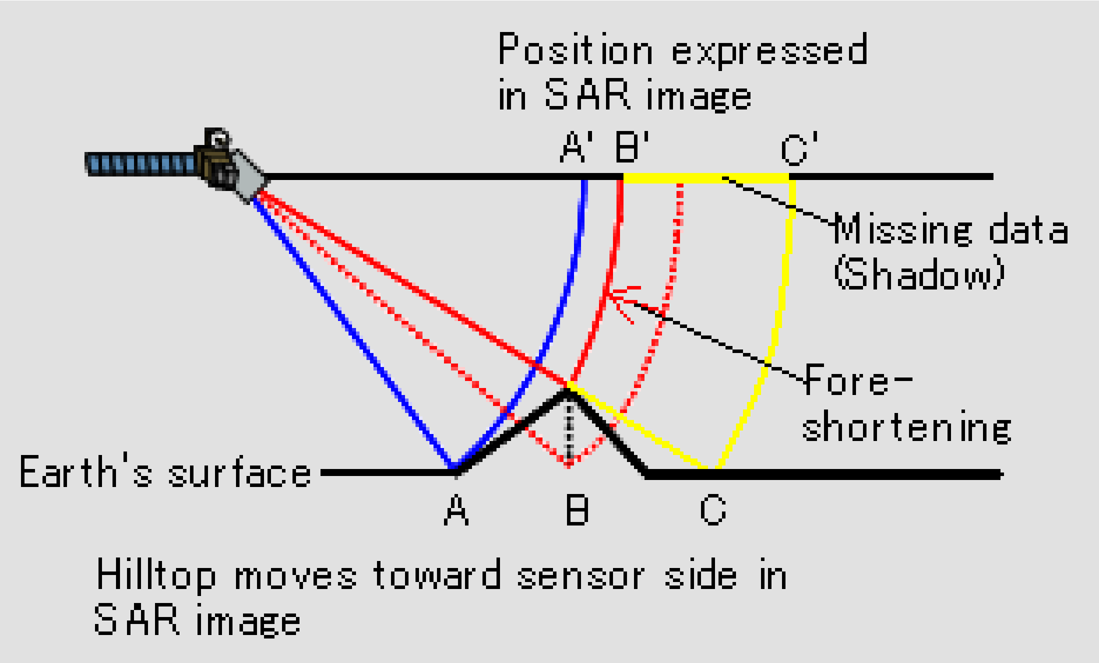
Imaging different types of surface with radar

From JPL/NASA Homepage http://www.jpl.nasa.gov/

0) What's SAR (Synthetic Aperture Radar)

4: Unique characteristics of SAR image

As SAR data contains not positional information, but a distance between sensor and feature on earth's surface expressed in phase, so a hilltop in a SAR Image moves toward the sensor (point B on the ground is expressed in B' in the SAR image. This phenomena is called "fore-shortening") . In addition to this limitation, area which cannot be seen from the sensor (line between B and C shown in the figure) is not able to express in SAR image (this area is called "shadow").



0)What‘s SAR(Synthetic Aperture Radar)

5: Interferometric SAR

SAR data originally involve both brightness and phase, and the data (Single look complex (SLC) SAR data)expressed as arrays of complex numbers. The modules of the complex values produce the traditional radar images where variations of the brightness (the amplitude of the signal) reflect spatial variations of the physical characterisitcs of the ground surface (the reflector). In each SAR image pixel, the phase (the argument of the complex value) represents a measure modulo-l/2 (l is the radar wavelength) of the distance between the radar antenna and the ground.

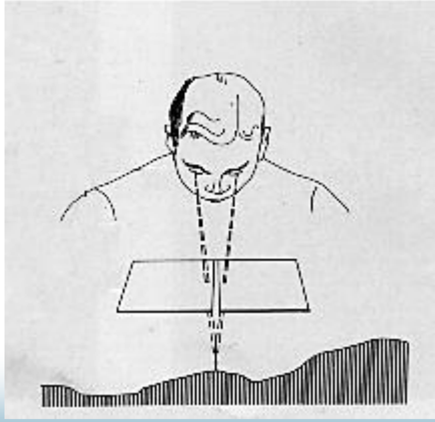
If the two images are acquired at two different times, the interferometric fringe is sensitive to any displacement of the ground parallel to the radar line of sight, occurring during the acquisition time interval. The sensitivity of the interferogram to topography increases with the interferometric baseline (the spatial separation of the two orbits), whereas the sensitivity to ground displacement is independent of the satellite configuration. For spaceborne systems, sensitivity to ground displacement is in general a few thousand times greater than the sensitivity to topography, allowing scientists to detect displacements of a few millimeters.

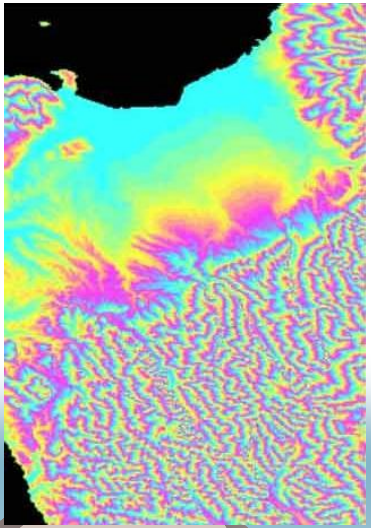
From JPL/NASA Homepage http://www.jpl.nasa.gov/

0）What‘s SAR（Synthetic Aperture Radar）

6: two ways to detect DSM using SAR data

There are 2 ways to develop DSM using SAR data. One is stereo-matching and the other is In-SAR analysis. Altitude of location of a certain object might be calculated using stereo-matching method. Although a position of the object shown in a SAR image is differ from that in an aerial photograph, similar method can be used if geometric difference among SAR and aerial photograph is considered. Also In-SAR analysis is available if two or more observations are performed at the same area and movement among those observations are correctly removed. If two observations are performed simultaneously, DSM would be detected more easily.





1）Development of DSM Detection with airborne SAR data

About GSI-SAR

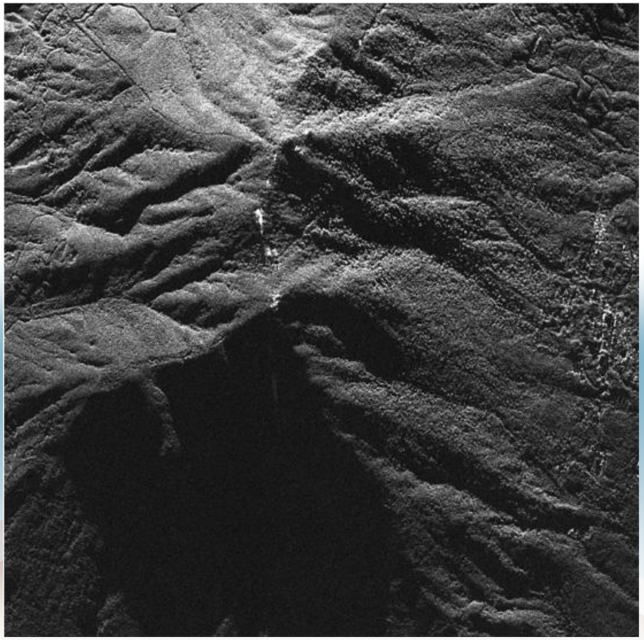
1）Development of DSM Detection with airborne SAR data

About GSI-SAR

Specifications：

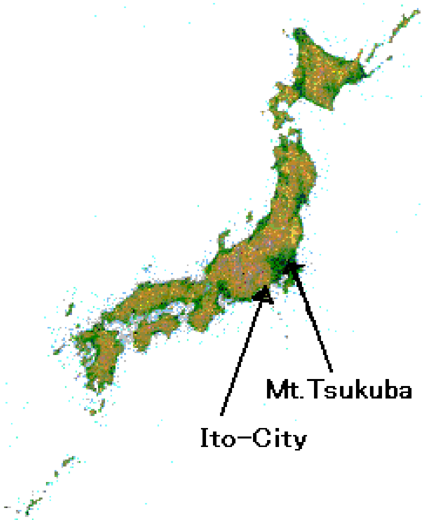
Frequency/Wavelength	9．555GHz（3．1cm）
Bandwidth	100MHz
Anntena gain	＞20dB
Anntena beam width	＞6°（horizontal), ＞25°（vertical)
Distance between anntenas	＞60cm
Off-nadir angle	55-75°
Polarization	HH
Resolution	Azimuth1.5m/Range:1.5m
Platform	Aircraft:Cessna-208-JA8212

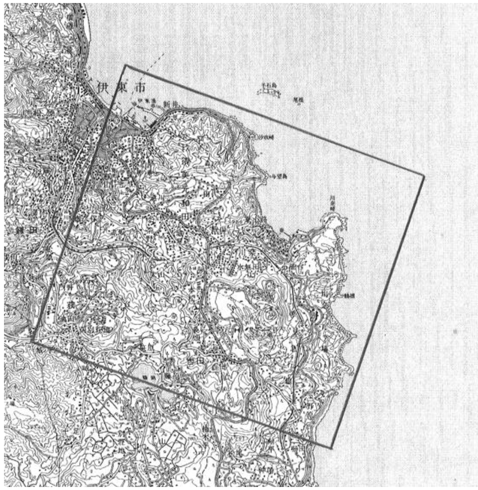
Example（Mt.Tsukuba）

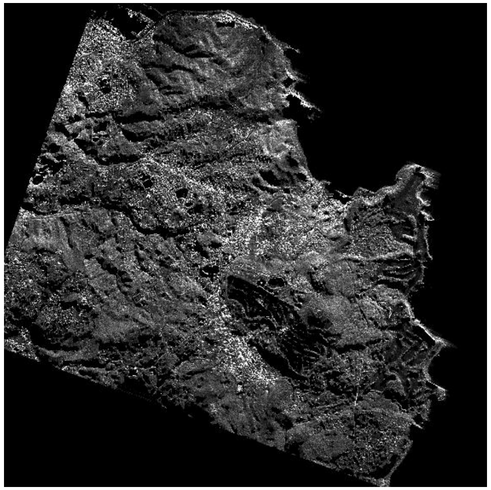


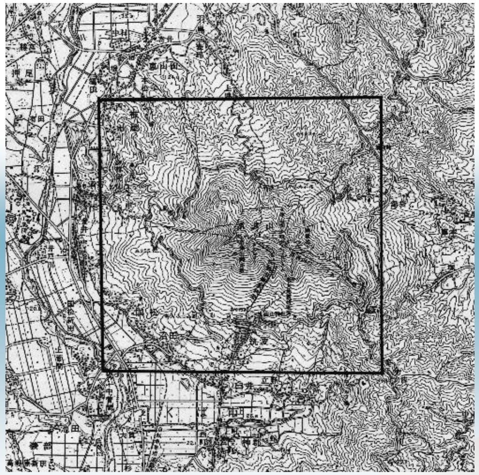
1）Development of DSM Detection with airborne SAR data

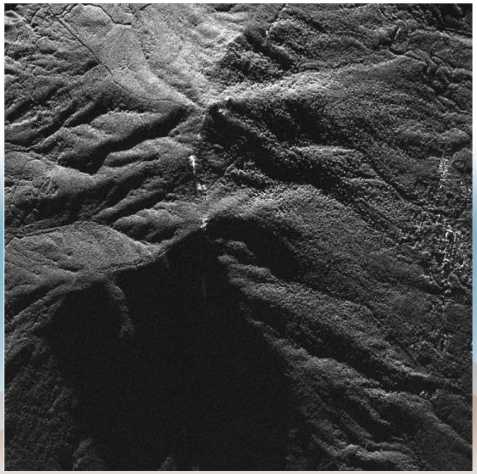
Obtained data：Ito City（Feb.1999）、Mt.Tsukuba（Oct.1999）











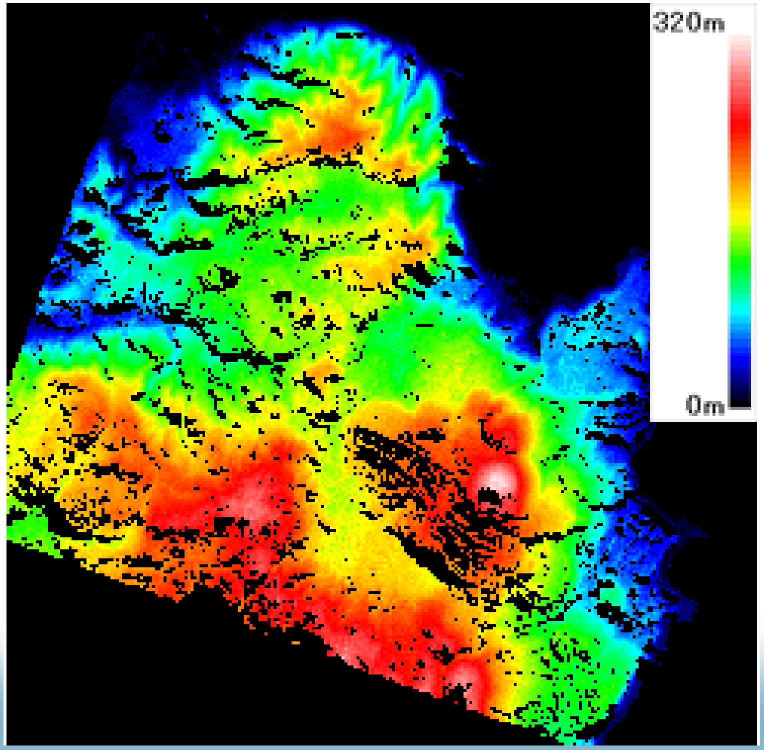
Upper: Ito City

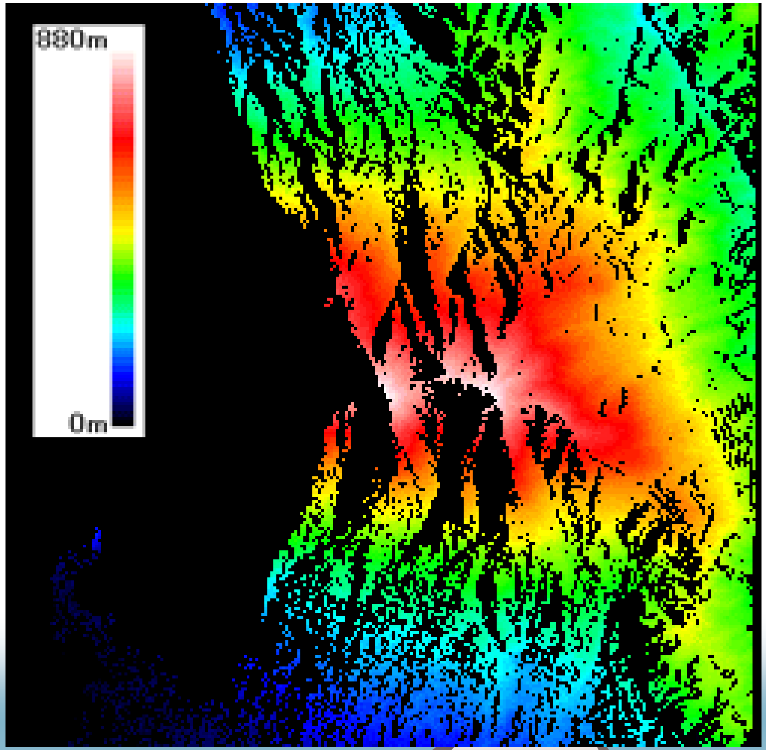
Lower: Mt.Tsukuba

1）Development of DSM Detection with airborne SAR data

DSM obtained by In-SAR analysis using simultaneously observed data

（Left: Ito City　Right: Mt.Tsukuba）



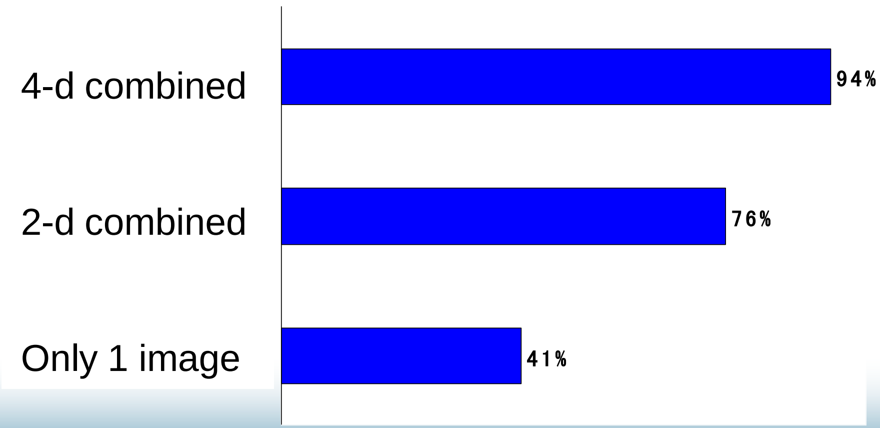


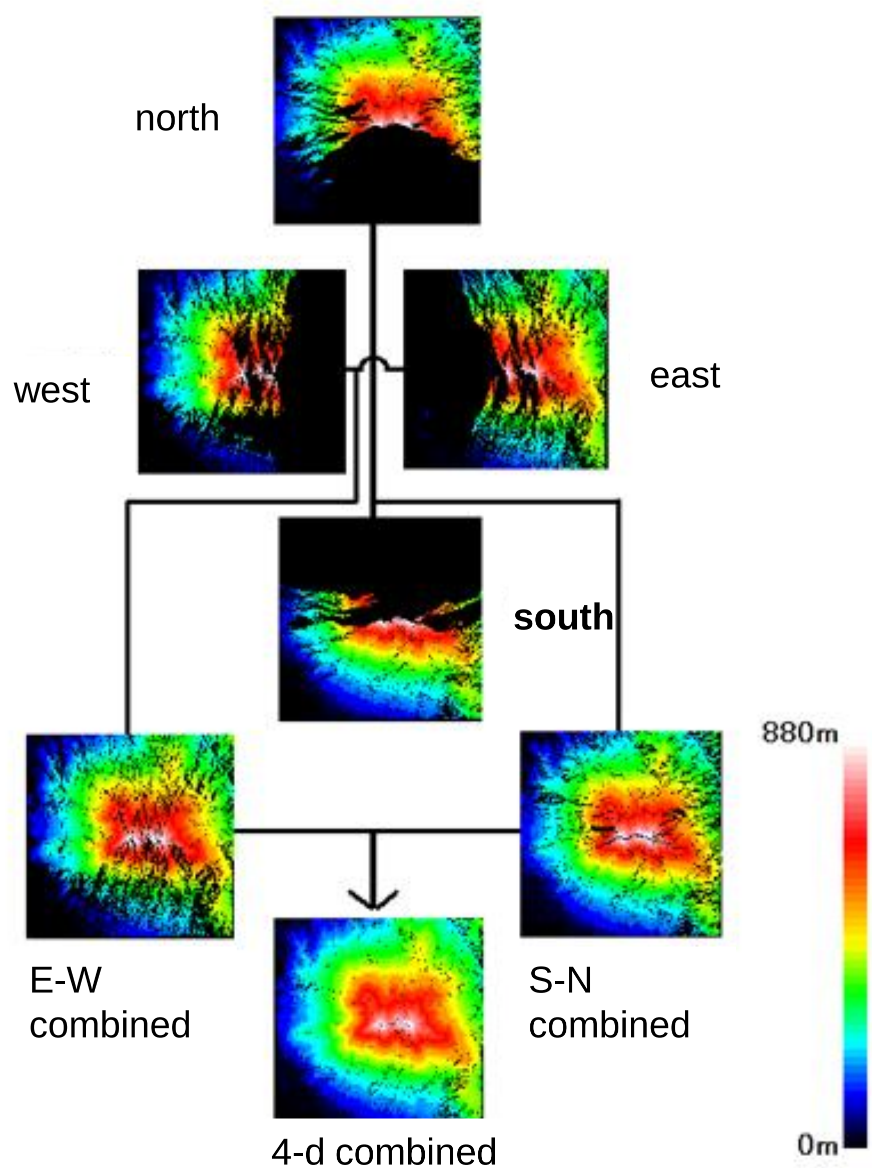
As topography in Ito City is not so steep, number of pixels data are lost is relatively small. On the other hand, in case of Mt. Tsukuba, there are many pixels that cannot be observed from the aircraft as topography is relatively steep. Whole topographic feature cannot be seen from this sole image.

1）Development of DSM Detection with airborne SAR data

4-directions observation data were combined to obtain whole topographic feature of Mt. Tsukuba

Ratio of data obtained at Mt. Tsukuba





1）Development of DSM Detection with airborne SAR data

Accuracy of DSMs were validated by comparing SAR's DSMs and DSM obtained by automatically stereo-matched aerial photographs (Residual between aerial photograph and GCP was less than 20cm).

(Unit：m)	Averaged residual (absolute value)	Standard deviation of residuals
Ito City	7.5	9.7
Mt. Tsukuba (E)	9.1	7.7
Mt. Tsukuba (W)	11.1	13.6
Mt. Tsukuba (S)	7.5	8.8
Mt. Tsukuba (N)	7.7	9.6
Mt. Tsukuba (E-W)	9.9	11.4
Mt. Tsukuba (S-N)	7.5	9.5
Mt. Tsukuba (4D)	7.4	9.0

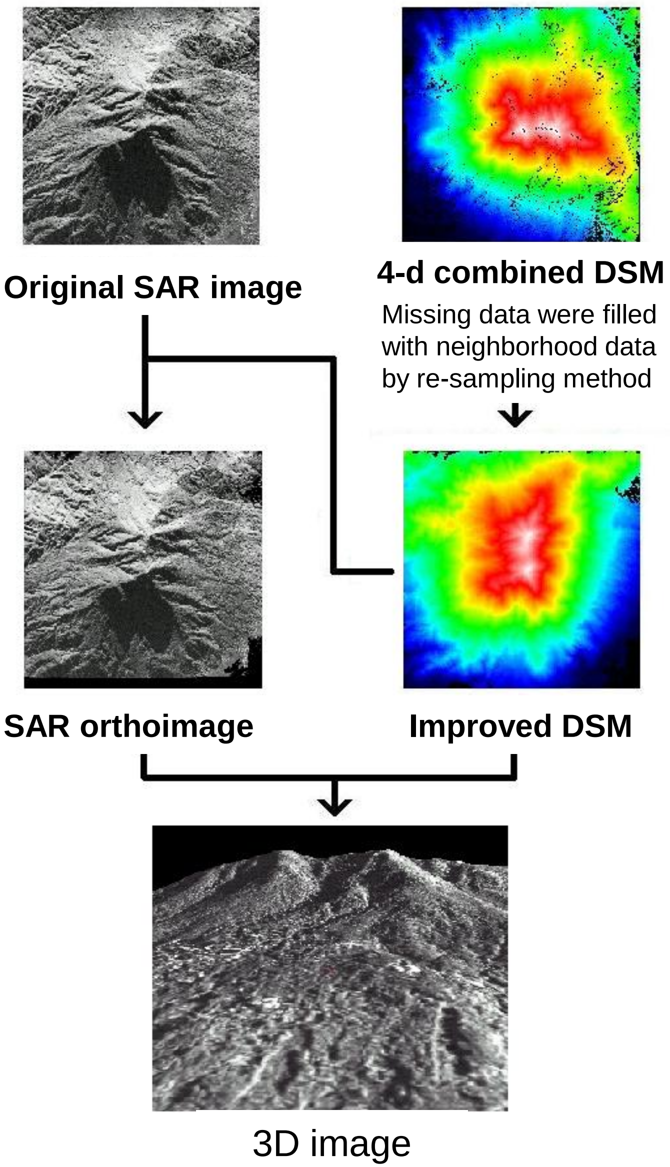
Standard deviations of residuals were around 10m, and this might allow us to apply SAR's DSM to 1:50,000 scale topographic map.

1）Development of DSM Detection with airborne SAR data

Application use

SAR image can be converted to orthoimage using positional information of platform.

Various information, such as flooding area and other disaster information, might be combined easily with this orthoimage SAR

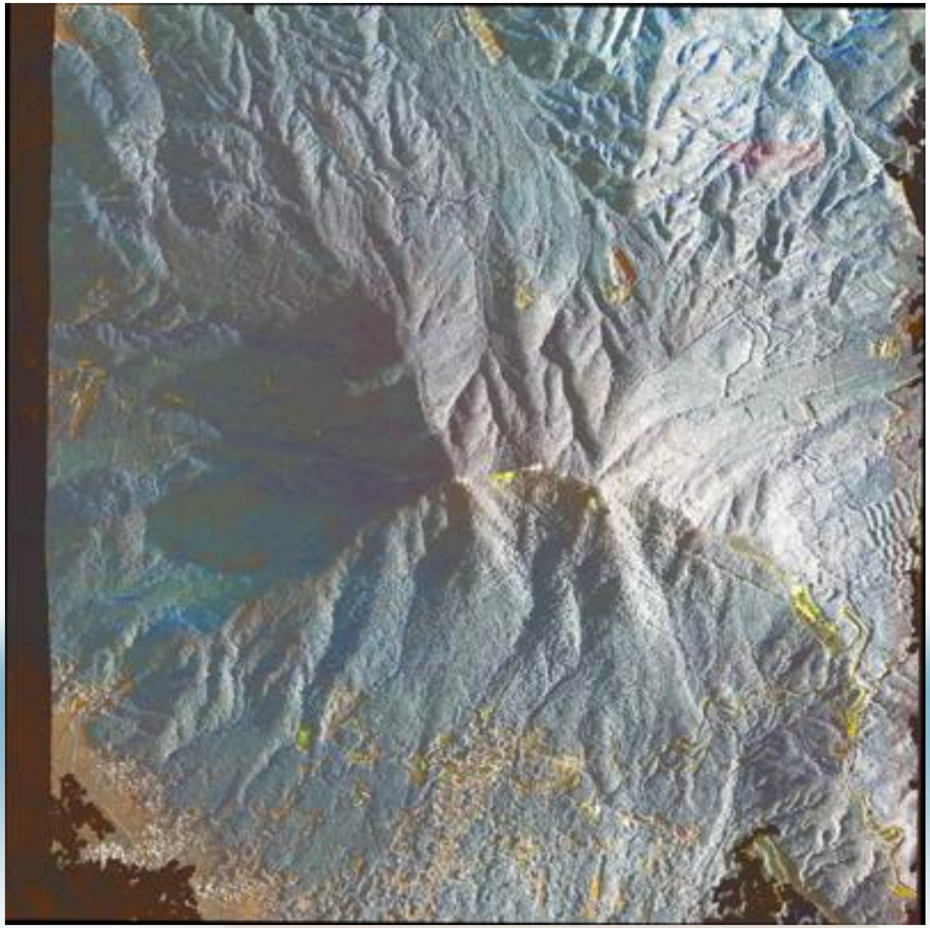


1）Development of DSM Detection with airborne SAR data

Application use

Image developed by SAR orthoimage and aerial photograph combined data which HSI conversion was performed.

Extent of disaster such as flood, might be detected effectively with information from not only hue and saturation in aerial photograph but intensity of back-scatters of microwaves.



1）Development of DSM Detection with airborne SAR data

Conclusion

・DSM with accuracy of around 10m might be obtained by airborne SAR

⇒Rough topographic feature can be obtained

・Whole topographic feature in steep area can be obtained with

4-directions observations

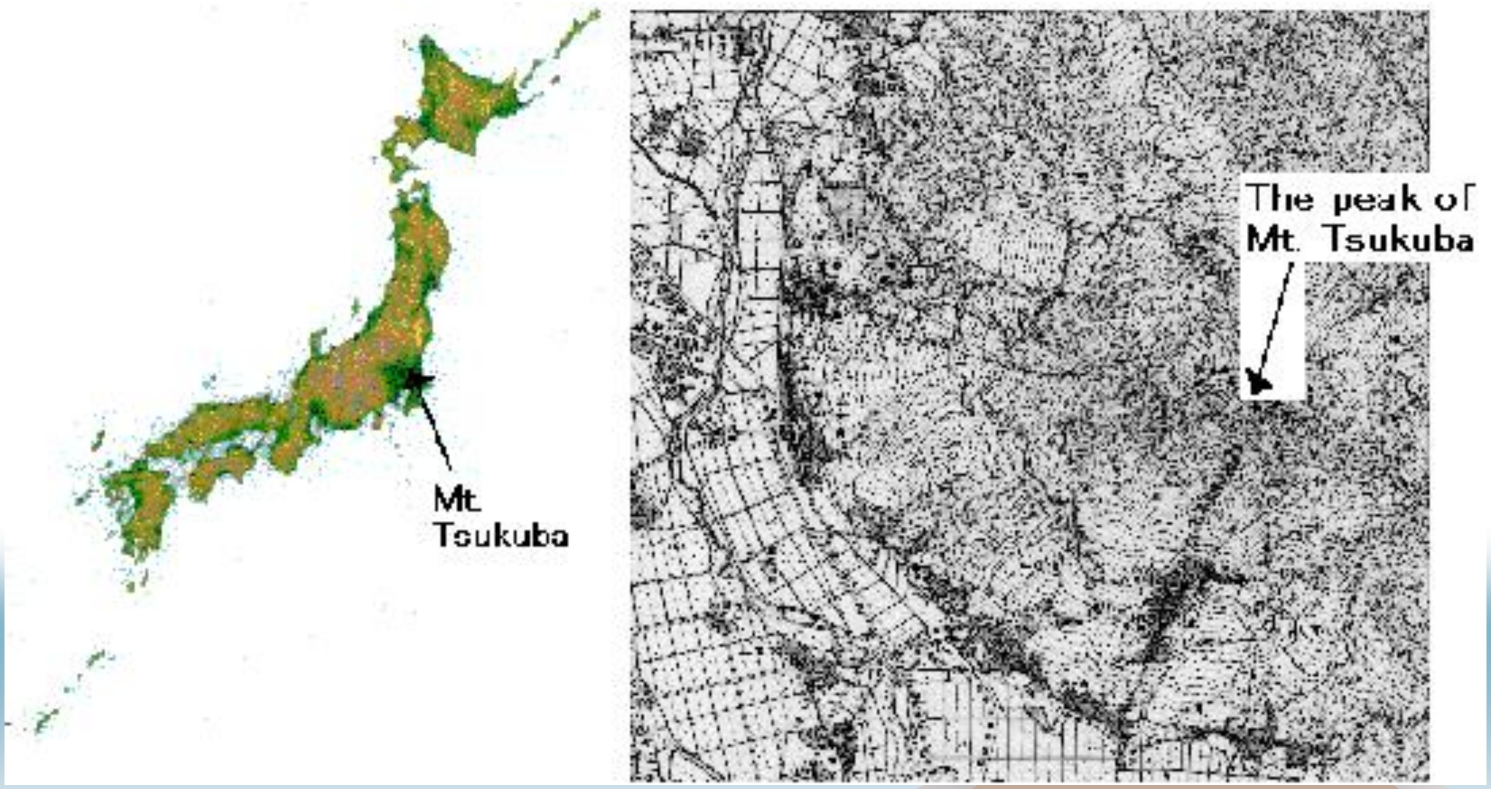
⇒This approach might be effectively applied in volcanic area

・Application use such as SAR orthoimage might be used for disaster detection

⇒SAR image is effectively used in case of bad weather as optical sensor cannot be obtain data under clouds

2）Development of DSM Detection with spaceborne SAR data

Study area is Mt. Tsukuba, the same as airborne's, but different way, stereo-matching method with information of back-scatter intensity was applied.



2）Development of DSM Detection with spaceborne SAR data

About RADARSAT

Specifications：

Frequency/Wavelength	5. 3GHz（5. 6cm）
Altitude of platform	798km
Inclination	98.6°
Repeat cycle	24days
Observation interval	7days
Polarization	HH
Resolution	Azimuth 9m, Range 9–11m (Fine Mode)

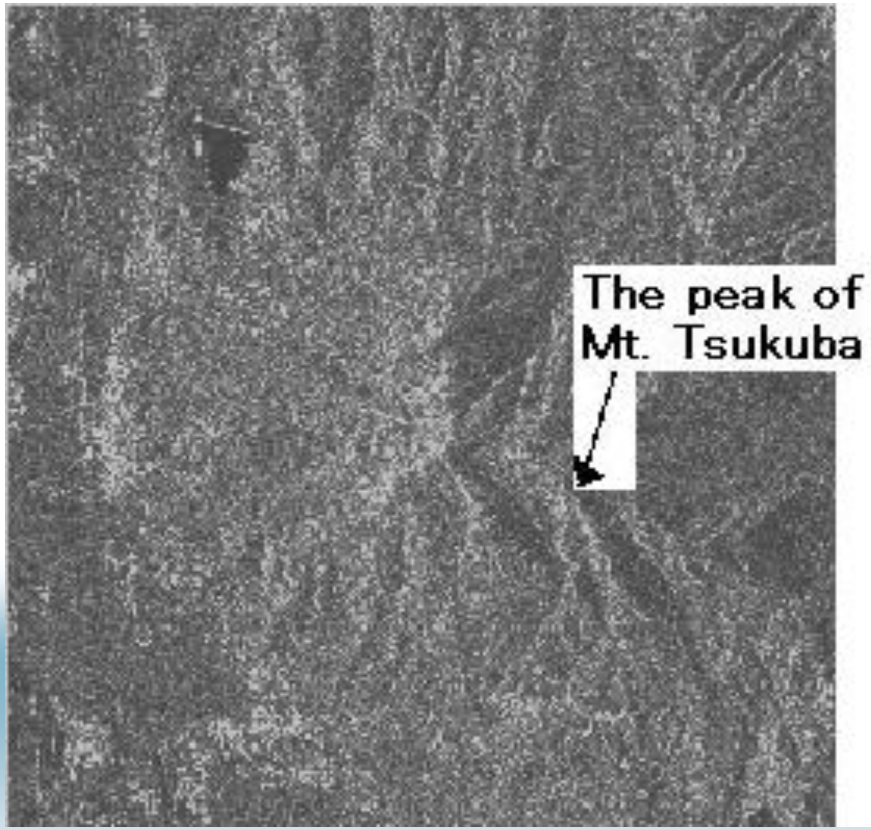
⇒Path image plus adopt detailed pixel spacing, 3.125m, which is smaller than resolution. This is because lower resolution would be brought if larger pixel spacing were adopt

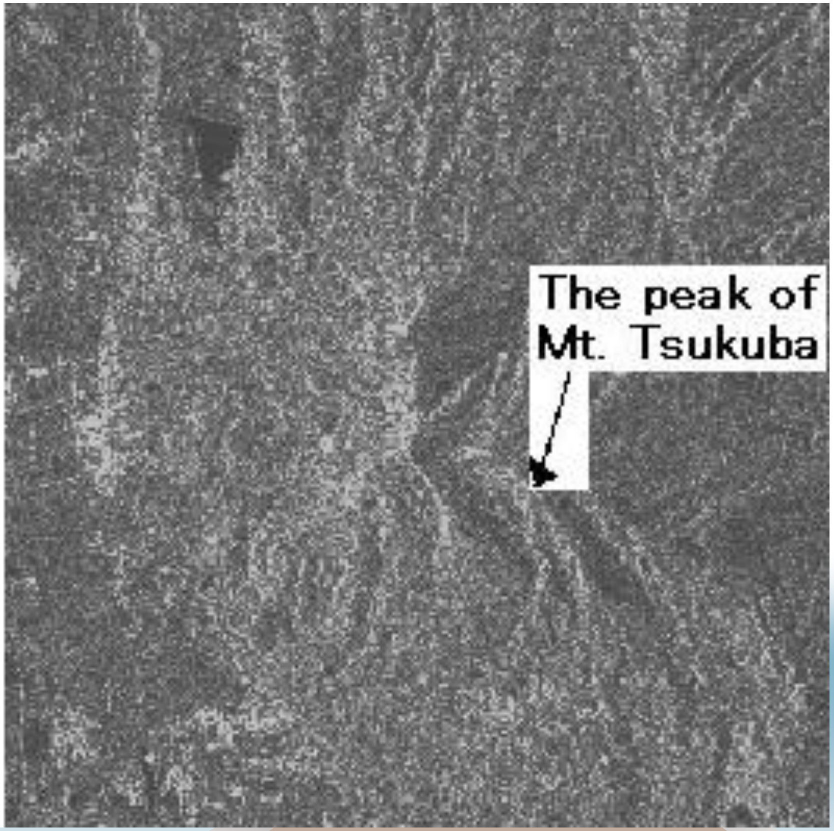
*Path image plus data were adopted at this time

2）Development of DSM Detection with spaceborne SAR data

SAR Image（unclear relative to airborne SAR because of low resolution）

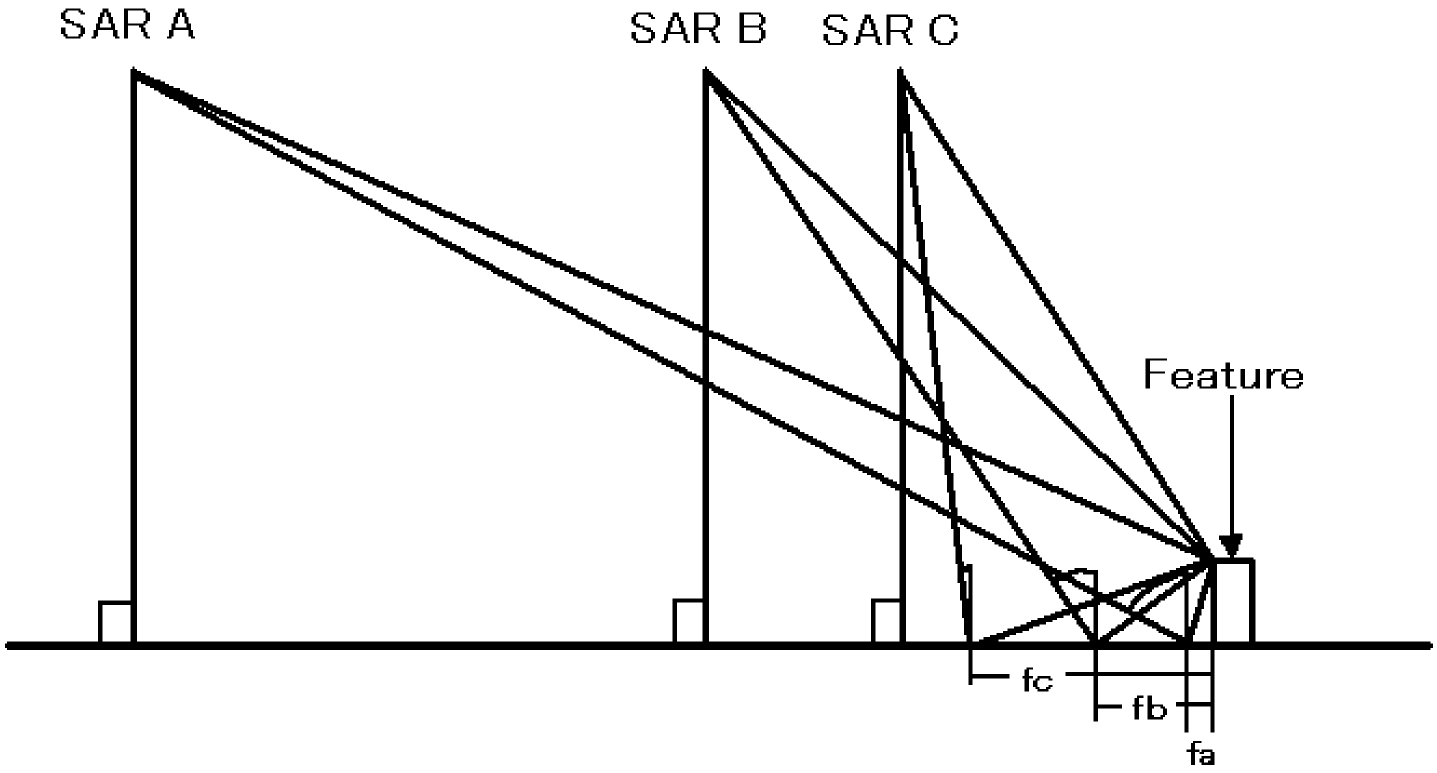
（Left：1998.12.22, Right：1998.12.29）





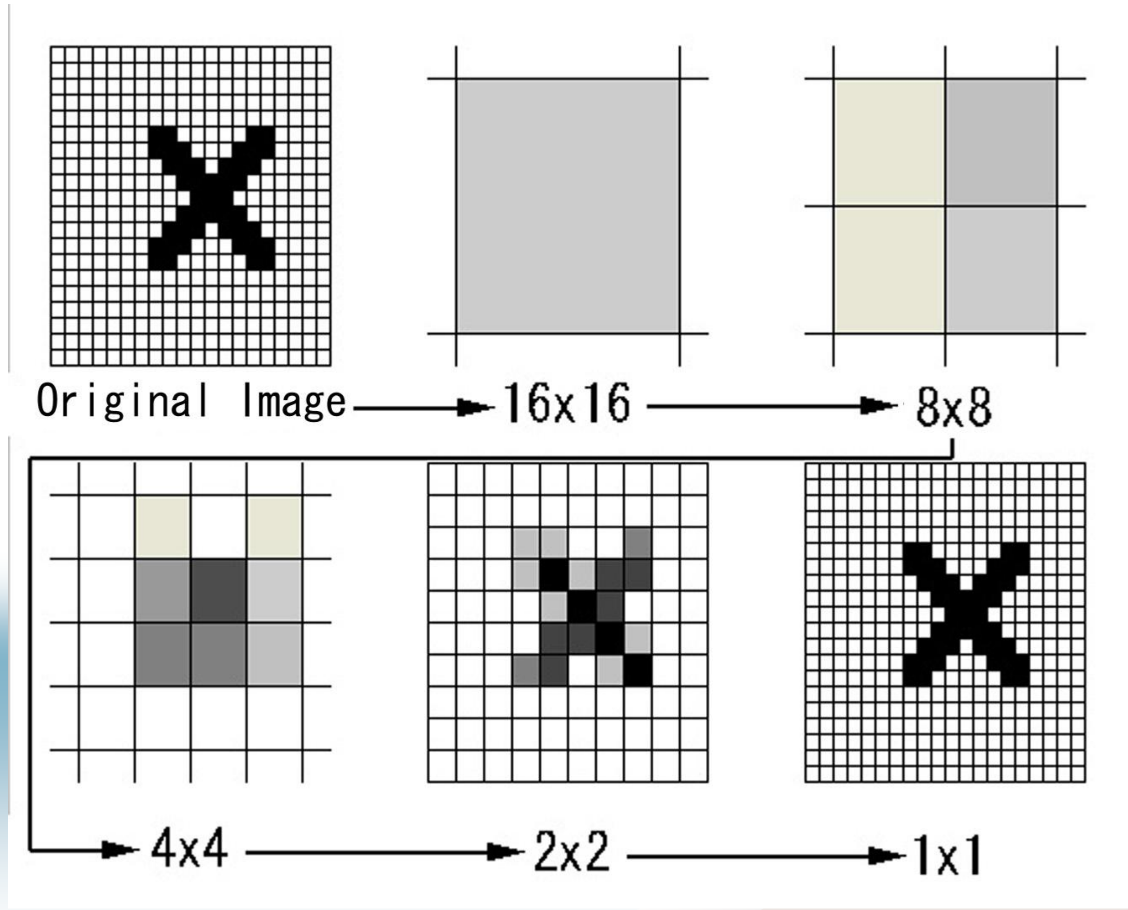
2）Development of DSM Detection with spaceborne SAR data

Altitude was calculated by orbit data of the platform and difference of fore-shortening values among observations



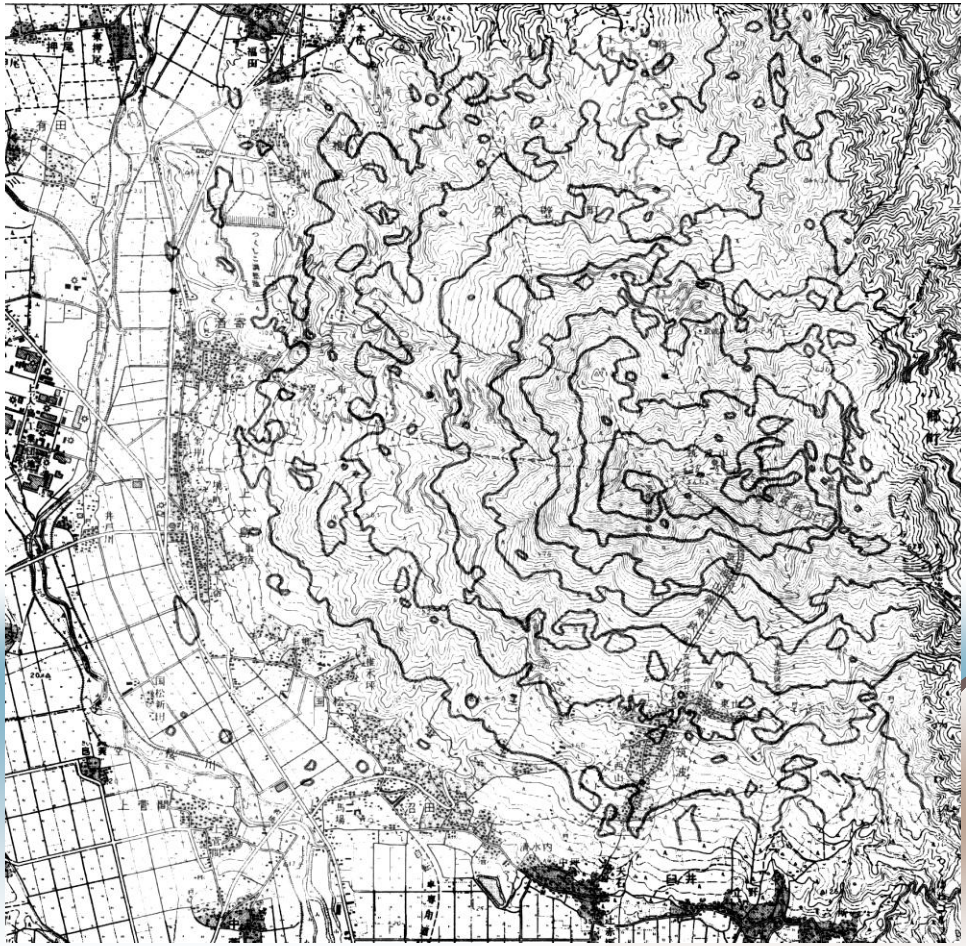
2) Development of DSM Detection with spaceborne SAR data

For stereo-matching SAR images, correlation analysis among images were performed at several resolutions to improve accuracy



2）Development of DSM Detection with spaceborne SAR data

Stereo-matching DSM from two RADARSAT images is as follows; the figure shows the relationship between SAR DSM and DSM by aerial photographs



2）Development of DSM Detection with spaceborne SAR data

Difference of 1 pixel (3.125m) fore-shortening corresponds altitude difference around 16m

⇒SAR DSM can detect approximate height at every 16m, such as, 0m, 16m, 32m…

Residuals of SAR DSM compared to air-photo DSM was around 30m in absolute average, and around 40m in standard deviation

⇒As DSM cannot detect detailed altitude difference less than 16m and 16m can be brought through higher resolution, 3.125m, while actual resolution remains 9m or so, this is understandable that calculated standard deviation of residuals remained around 40m

*As difference of incidence angle between two images were around 5 degrees, altitude difference smaller than 16m could not be recognized. If images with larger incidence angle difference were adopted, detectable height difference could be smaller (But if images with larger incidence angle difference were adopted, coherence between images would be worsen and this might deteriorate quality of DSM).

2）Development of DSM Detection with spaceborne SAR data

Conclusions

・Rough topographic feature (with c.a. 40m standard deviation in residuals) was detected by RADARSAT images with stereo-matching method

Future improvement of DSM can be expected as satellite with more detailed SAR sensor will be launched. Also, proper selection of stereo-pair images might improve roughness of created DSM by SAR, if images with larger incidence angle difference were adopted, detectable height difference could be smaller

Conclusions

- Detection of DSM by airborne SAR with In-SAR analysis and by spaceborne SAR with stereo-matching method were performed
- Accuracy of DSM were around 10m for airborne SAR and 40m for spaceborne SAR. This difference was thought to be brought mainly by difference in resolution
- In spite of DSM by RADARSAT images was not so accurate, improvement would be expected as some satellites with higher resolution will be launched in the near future

Thank you for your attention !