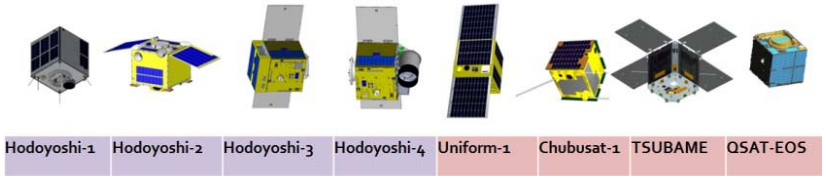
Environment Monitoring of Fukushima and Chernobyl Areas using a Constellation of Earth Observation Microsatellites

Japan-Ukraine Cooperation Technical Demonstration Program
for Supporting Aftermath Responses to Accidents at Nuclear Power Stations



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The University of Tokyo
November 20th , 2013
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Fukushima and Chernobyl areas have catastrophic nuclear disasters and need careful long term monitoring of radiation and environment change

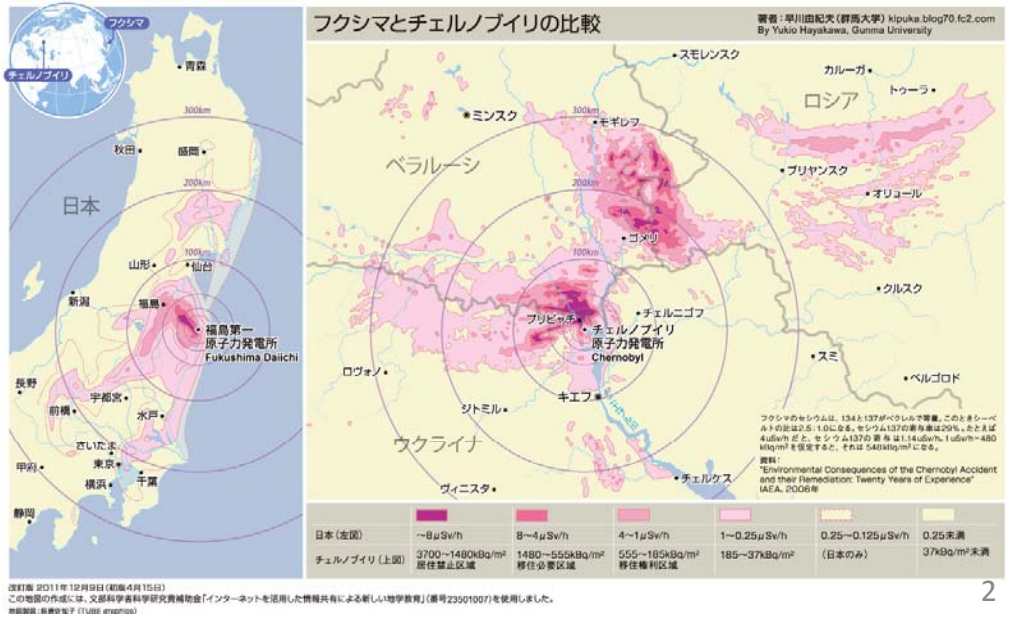
- ALOS - Japan's main Earth observation satellite *(4000kg)* stopped its function just after the Fukushima disaster. ***Alternative satellites?***
- Hodoyoshi microsatellites development started:
  small *(50 to 60kg each),* simple, low cost, short lead-time technology satellites.

  " Can we prepare a constellation of microsatellites that can quickly respond to national catastrophes?
  The microsatellite constellation can observe wide geographical areas frequently, regardless of international borders and access restrictions."

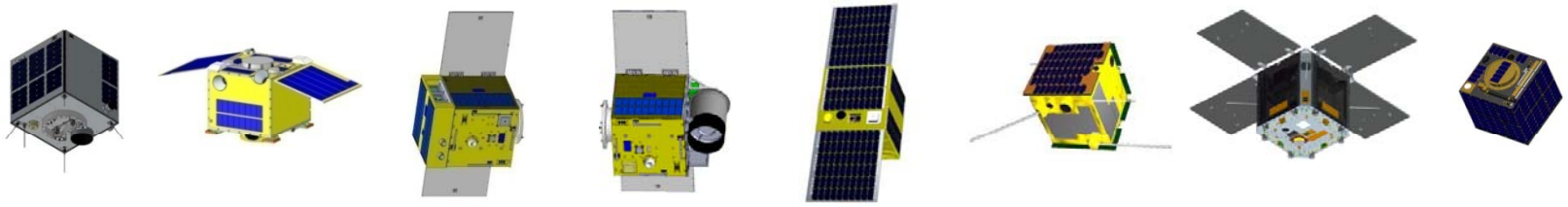
→ Preparation of a Constellation of Earth Observation Microsatellites (hardware)

" What kind of satellite observations and analysis are really useful for Fukushima?
Let's learn from Ukrainian experience of monitoring and management of Chernobyl."

→ Cooperation with Ukraine
(application and software)



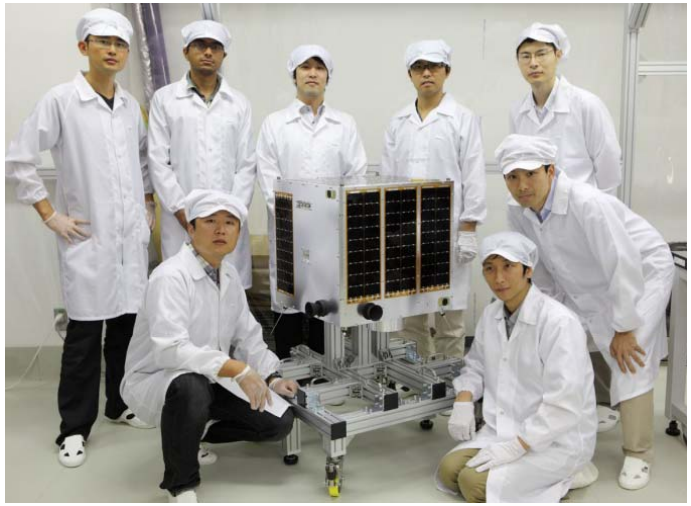
Constellation of Earth Observation Microsatellites of Japanese Universities for Environment Monitoring of Fukushima and Chernobyl Areas

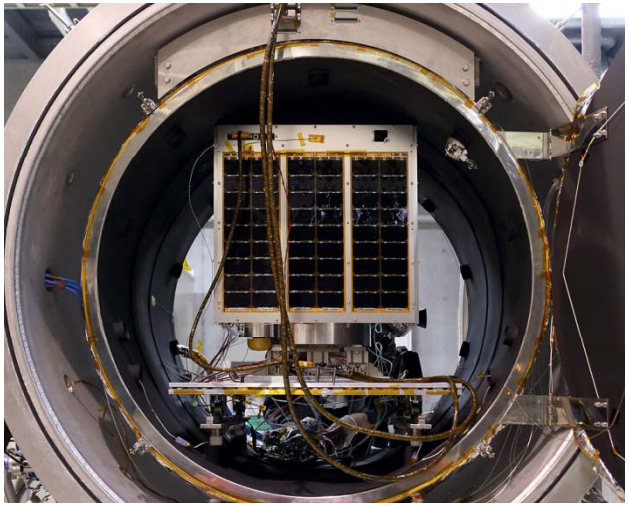


Satellite name	Hodoyoshi-1	Hodoyoshi-2	Hodoyoshi-3	Hodoyoshi-4	Uniform-1	Chubusat-1		TSUBAME	QSAT-EOS
Organization	The Univ. of Tokyo	Tohoku Univ. The Univ. of Tokyo	The Univ. of Tokyo		Wakayama Univ. The Univ. of Tokyo	Nagoya Univ. Daido Univ.		Tokyo Inst. Tech.	Kyusyu Univ.
Attitude Control	3axis (RW)	3axis (RW)	3axis (RW)	3axis (RW)	3axis (RW)	3axis (RW)		3axis (CMG)	3axis (RW)
Optical sensor	Multispectral	Variable Multispectral	Multispectral	Multispectral	Thermal infrared	Thermal infrared	RGB color camera	RGB color camera	2 band Multispectral
GSD	6.8m/pixel	5m/pixel	38m/pixel	6.3m/pixel	200m/pixel	150m/pixel	10m/pixel	10m/pixel	7m/pixel
Swath width	27.8km	3km	80km	25.2km	128km	96km	20km	20km	10km
Spectral band	4 bands	Variable	3 bands	4 bands	1 band	1 band	3 bands	3 bands	2 bands
	B1: 450-520	B1:420-700nm	B1: 520-600	B1: 450-520	Thermal IR	Thermal IR	RGB color	RGB color	B1: 450-550
	B2: 520-600	B2:650-1000nm	B2: 630-690	B2: 520-600					B2: 780-920
	B3: 630-690		B3: 730-900	B3: 630-690					
	B4: 780-890			B4: 730-900					
S&F data collection		Yes	Yes	Yes					
Status	Ready for launch	FM integration	FM integration		FM integration	Ready for launch		Ready for launch	Ready for launch
Orbit	SSO 522km	SSO	SSO 630km	SSO 630km	SSO 630km	SSO 529km		SSO 541km	SSO 536km
Launch	Early 2014 Dnepr	(2014-5) (H2A)	Spring 2014 Dnepr	Spring 2014 Dnepr	Early 2014 H2A	Early 2014 Dnepr		Early 2014 Dnepr	Early 2014 Dnepr

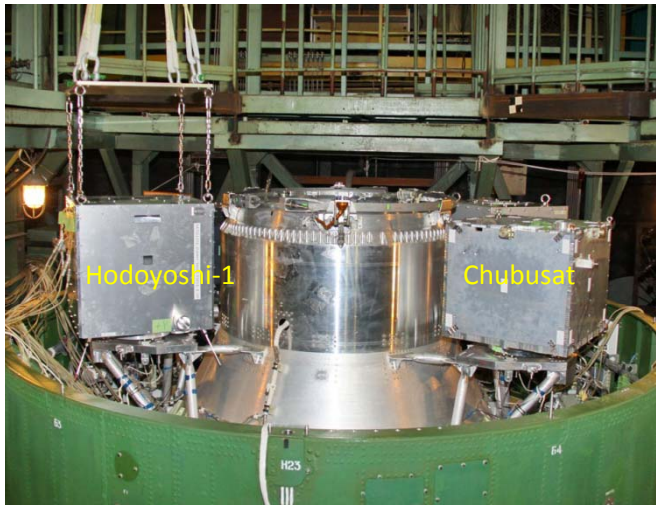
Each microsatellite has a mass of 50kg to 60kg, a size of 50x50x50cm or little larger. Each has three axis attitude control using reaction wheels or a Control Moment Gyro. Each will carry different types of optical Earth observation sensors from visible to infrared. Hodoyoshi-2, -3, -4 carry S&F data collection platforms. Flight Models of four satellites (Hodoyoshi-1, Chubusat-1, Tsubame, QSAT-EOS) are completed, and other four FMs (Hodoyoshi-2, -3, -4, Uniform-1) are being integrated and tested. Most of them will be launched in early next year by Dnepr launch vehicles , and some of them by H2A

Preparation of Microsatellites and their Launches



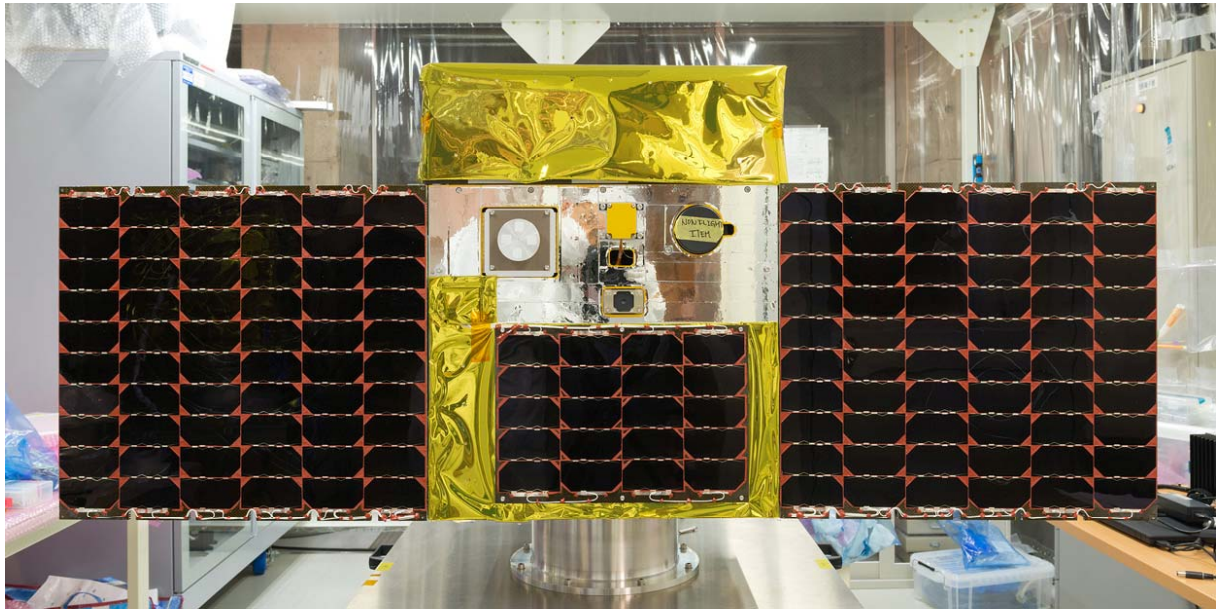


Hodoyoshi-1 FM and its Vibration Test and Thermal Vacuum Test

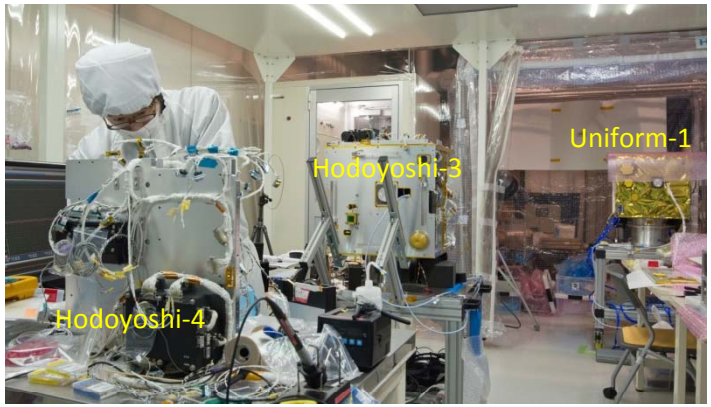
Fit check and Combined Environment Tests with Dnepr Launch Vehicle at SDO Yuzhnoye in Ukraine were completed successfully
(Structure models of Hodoyoshi-1, Chubusat-1, Tsubame, Qsat-EOS)
Flight Models of four satellites are ready for the piggyback launch by Dnepr vehicle in early 2014 from Yasny launch site.

Preparation of Microsatellites and their Launches



Hodoyoshi-3 FM

Thermal Vacuum Test of Uniform-1 FM



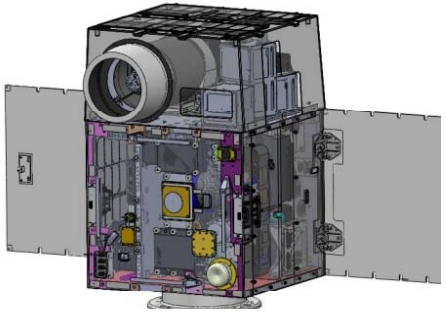
Integration of Hodoyoshi-3, -4, and Uniform-1 FM

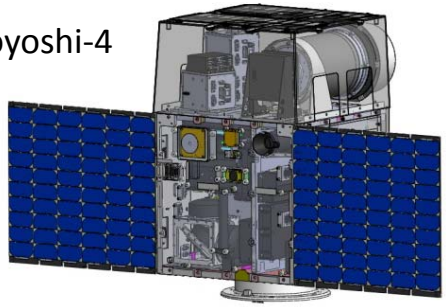
Dnepr Launch Vehicle
and Members of Cluster Launch

Hodoyoshi-3 and -4 will be launched by Dnepr launch vehicle in a cluster launch in spring 2014 from Yasny launch site, Uniform-1 by H2A in a similar time period from Tanegashima space center.

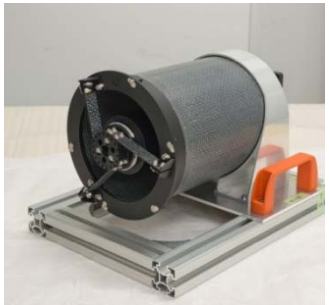
Preparation of Microsatellites and their Launches

- In spite of small size and low cost, each microsatellite has reasonable capabilities for the monitoring of Fukushima and Chernobyl.
- Hodoyoshi-4, to play major roles in the monitoring, carries most advanced equipment, with reasonable cost and reliability, developed in Hodoyoshi program using Japanese commercial technology.
  - 6m GSD multi-spectrum sensor (@600 km altitude);
  - Precision and high-agility 3-axis attitude control using compact SOI-SoC on-board computers, reaction wheels, a star tracker, a fiber optical gyro, and a GPS receiver;
  - Xenon Micro Ion Propulsion System;
  - 100M to 320Mbps 16QAM X-band data transmitter





Hodoyoshi-4

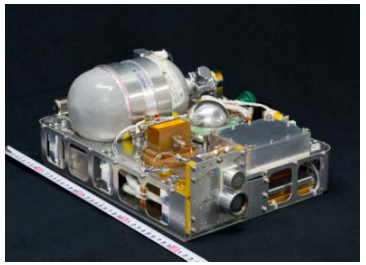


Multi-spectrum sensor

Star tracker

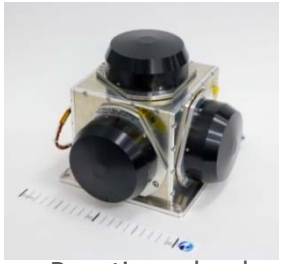
GPS Receiver

Fiber optical gyro



Micro Ion Propulsion System

SOI-SoC on-board computers,

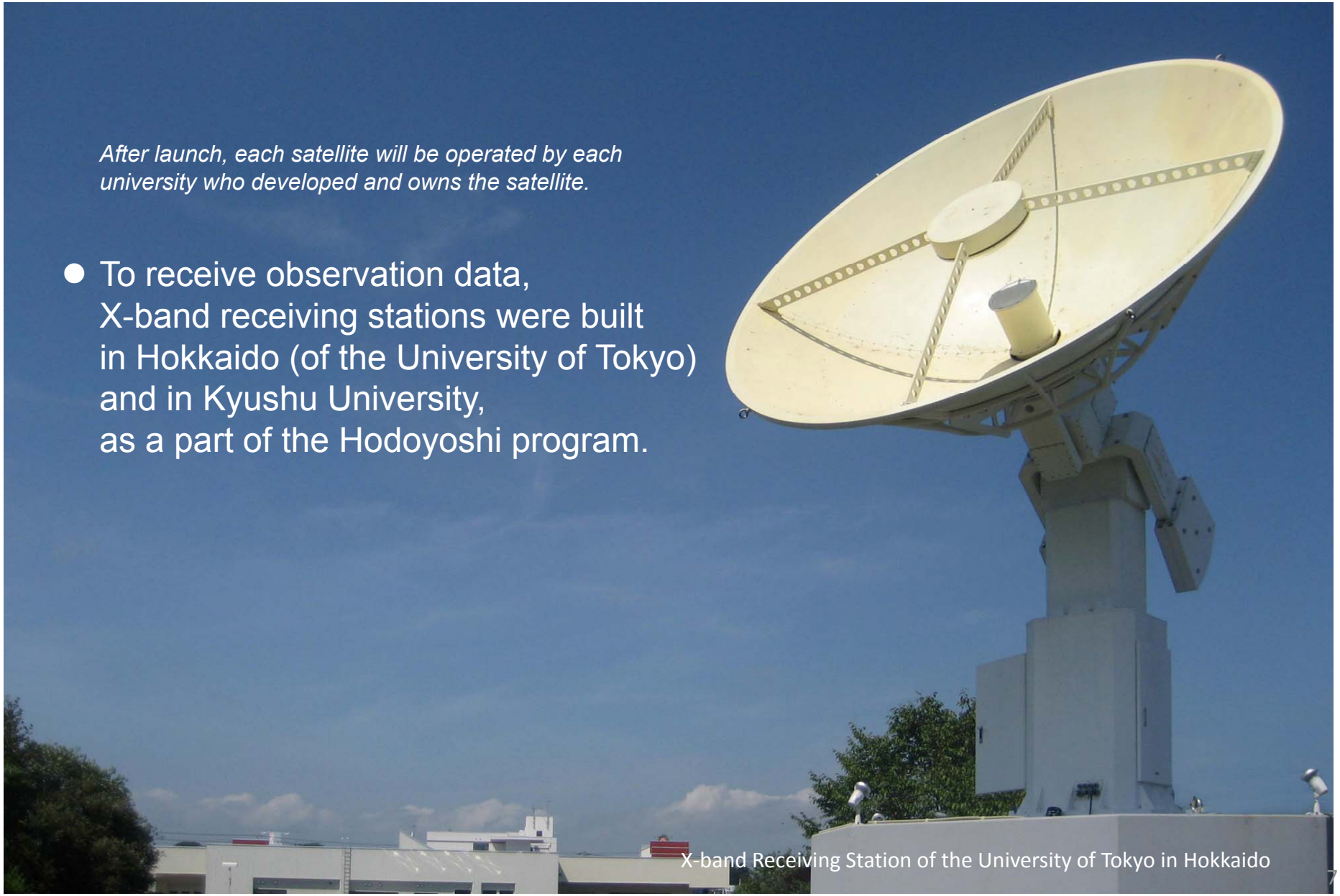


Reaction wheels

Preparation of Ground Segments

After launch, each satellite will be operated by each university who developed and owns the satellite.

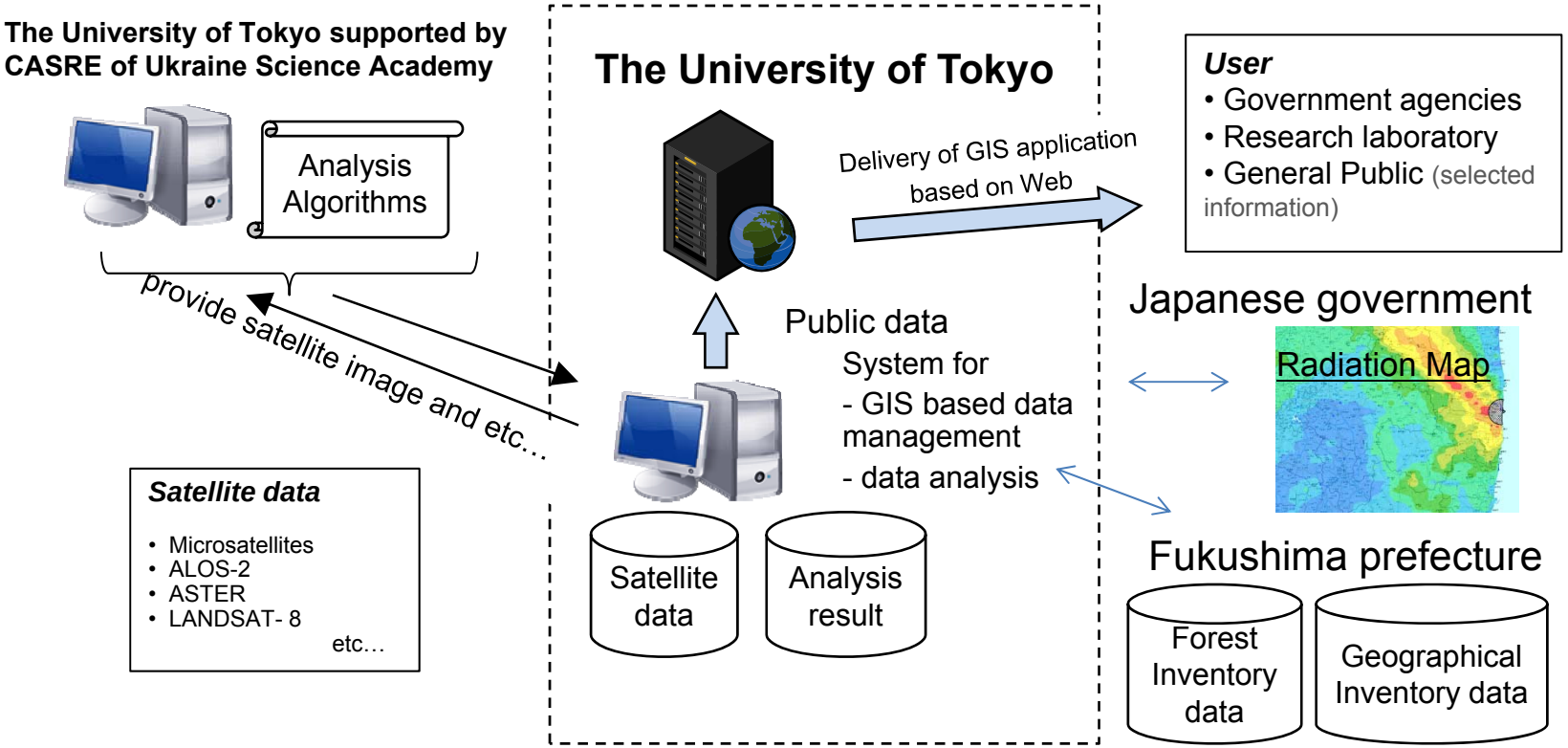
- To receive observation data,
  X-band receiving stations were built
  in Hokkaido (of the University of Tokyo)
  and in Kyushu University,
  as a part of the Hodoyoshi program.



X-band Receiving Station of the University of Tokyo in Hokkaido

Centralized Information System for Data Analysis and Distribution

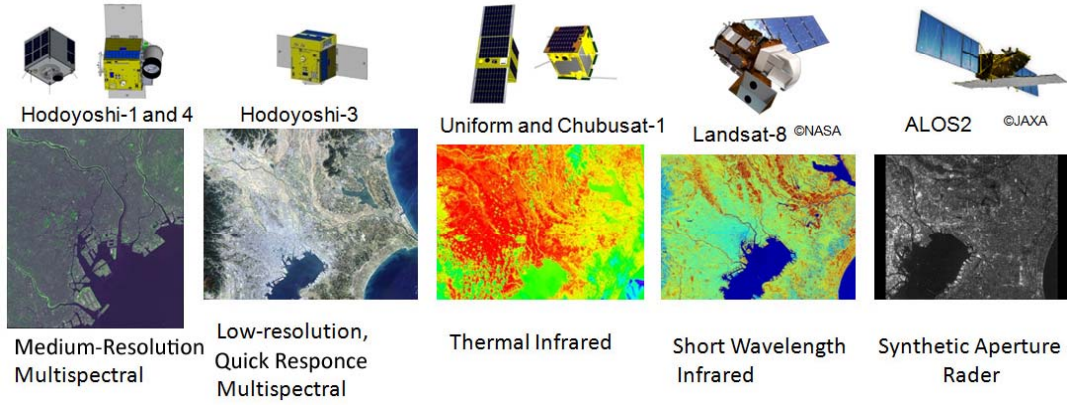
- The system will include satellite data, analysis algorithms, analyzed results, radiation maps, etc.
- Major results will be open to users in government and general public (selected information) through internet web-sites.



What can be Monitored by the Microsatellite Constellation to Support Aftermath Responses?

Using Observation Imagers

- The observation data will be gathered to a team at Iwasaki Laboratory of the University of Tokyo for analysis.
  (SWIR by Landsat-8 and SAR by ALOS-2 will also be used .)



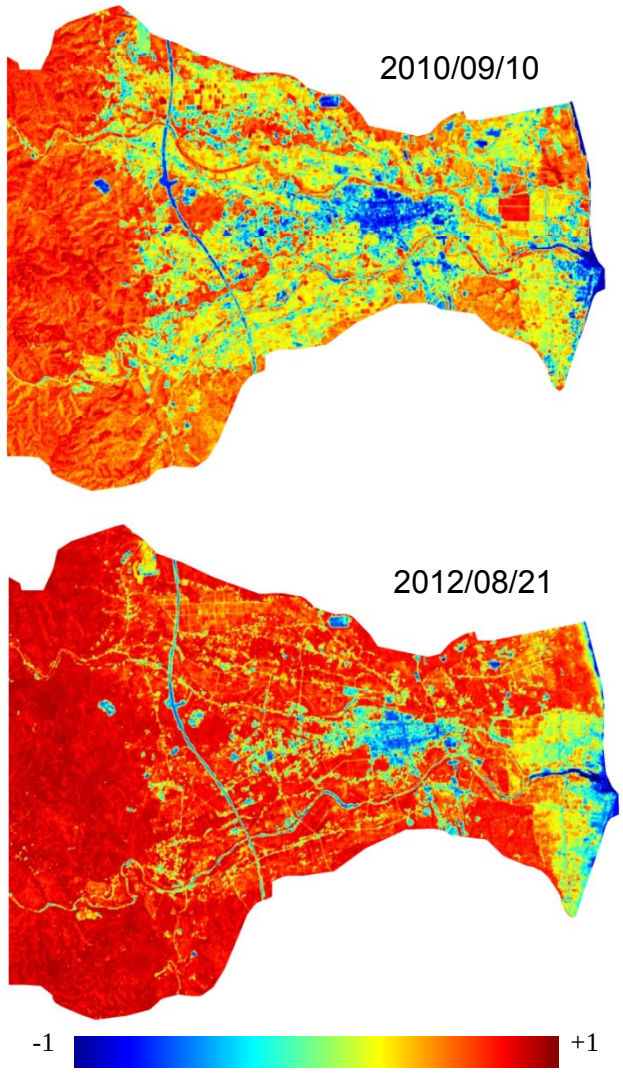
Major Objectives for the observation will include:

- Damage, recovery, and status of ground objects by visual interpretation.
- Environment of land cover, vegetation and water bodies (including symptoms of human interaction) by spectral analysis using such as:
  - NDVI *(Normalized Difference Vegetation Index),*
  - NDWI *(Normalized Difference Water Index),*
  - REP *(Red Edge Position)*
- Temperature around the nuclear stations by thermal infrared images.
- Others (to learn from Chernobyl experience)

What can the Microsatellite Constellation Monitor in order to Support Aftermath Responses?

Vegetation Change Before and After Accident (Satellite Observation)

Preliminary Analysis using ASTER data around Namie-cho, Fukushima



NDVI (Normalized Difference Vegetation Index)

- Vegetation index increased drastically from 2010 (before accident) to 2012 (after accident)
- Field-survey revealed that there were many abandoned rice fields with full of weeds.
- Increase of vegetation area could be caused by decrease of human activity.

Abandoned Rice Paddy in Fukushima (Mar. 2013)

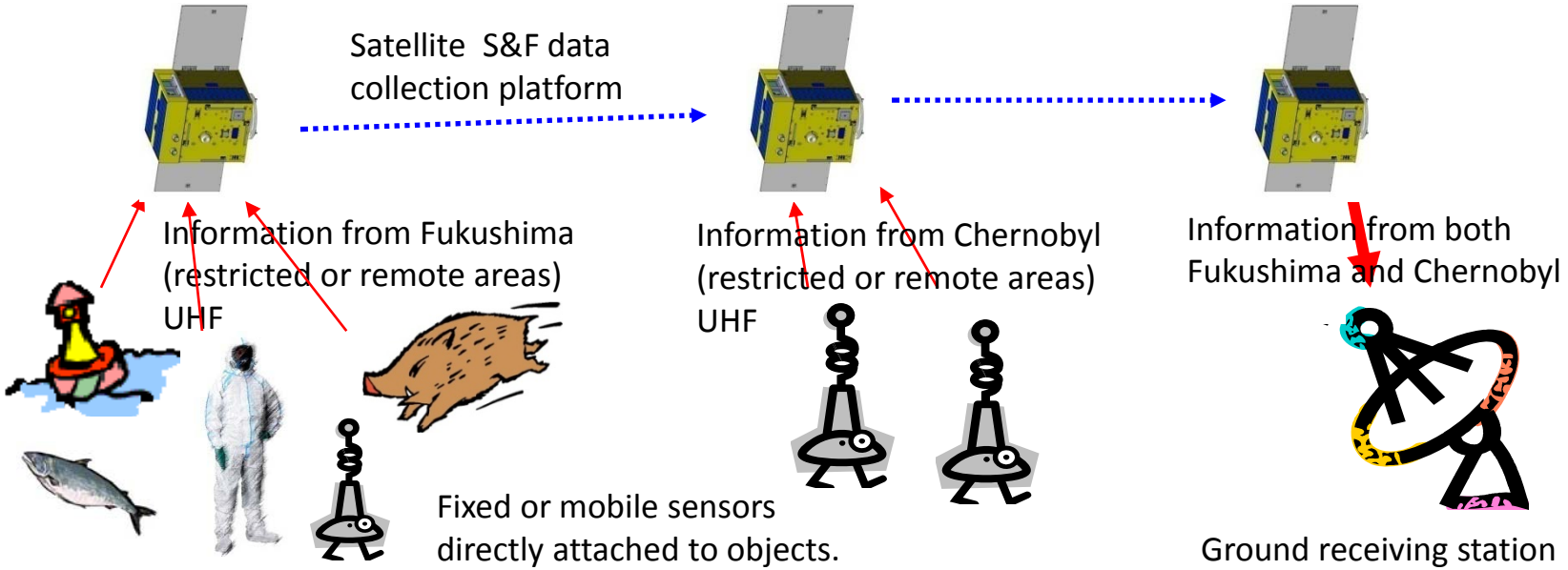
What can be Monitor using Microsatellite Constellation to Support Aftermath Responses?

Using Store and Forward (S&F) satellite data collection platform

Although the radiation intensity on the ground cannot be measured directly from satellite altitude,

S&F data collection platforms and ground installed sensors can gather radiation intensity in restricted areas or remote areas (including mountain areas and ocean).

- Radiation sensors can be attached onto the objects directly and continuously (unlike air-space radiation measurement by using helicopters)
- Low-cost sensors can be attached to even moving objects, people, animals, fish, buoys, etc.
- Data from both Fukushima and Chernobyl can be collected simultaneously .



International Space Cooperation with Ukraine

2000	2005	2010	2015

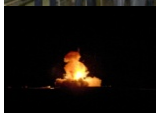
Ground Work
●SSAU

Launch of 10 Japanese Satellites by Russian/Ukrainian Dnepr and Cyclone-4

Launch 2005
■OICETS
■INDEX

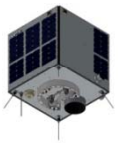
2007
●Study for MEXT






■Satellite A
■Hodoyoshi1
■Chubusat1
■Tsubame
■Qsat-EOS

launch 2014

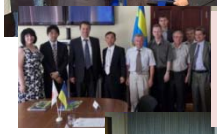




launch 2014

■Hodoyoshi3
■Hodoyoshi4

launch 2015

■Nano-JASMINE



Joint Observation Program using Microsatellites

●Oct. 2010, Kiev: *MOU for joint demonstration of Micro Earth Observation Satellites signed*

●June 2012: *Joint demonstration program for environment monitoring of Fukushima / Chernobyl areas started.*

●July 2012 Tokyo: ***First meeting of joint Japan-Ukraine committee*** *for the cooperation to advance aftermath response to accidents at nuclear power stations*

●December 2012 and February 2013: *Meetings with NAS, and MEU in Kiev*

●February 2012: *MEXT started small financial support to this program.*

●February 2013, Tokyo: *Ukrainian Chernobyl specialists invited to the University of Tokyo for* ***the first workshop and Fukushima field survey****.*

●July 2013, Kiev :***Second meeting of joint Japan-Ukraine committee, Chernobyl field survey, and the second workshop***

●November 2013, Tokyo :*Ukrainian Chernobyl specialists invited to the University of Tokyo* ***for the third workshop***

Space cooperation with Ukraine started 10 years ago with the launch of Japanese satellites by Dnepr launch vehicles made in Ukraine. The constellation will launch 6 microsatellites by Dnepr LV. Joint observation program actually started last June. Since then several meetings have been held.

Cooperation with Ukraine: National Academy of Science and State Agency on Exclusive Zone Management

First Workshop at the University of Tokyo

Joint Field Survey of Fukushima Exclusive Zone
(coastal area, flat area, mountain area)

First joint workshop and field survey of Fukushima exclusive zone in Feb 2013.

Cooperation with Ukraine: National Academy of Science and State Agency on Exclusive Zone Management

Second Workshop at the Ukraine Science Academy

Joint Government Meeting in Kiev

Field survey of Chernobyl Exclusive Zone

Abandoned City and Hot Spot

The second workshop in July 2013 and joint government meeting in in Kiev with Chernobyl field survey .

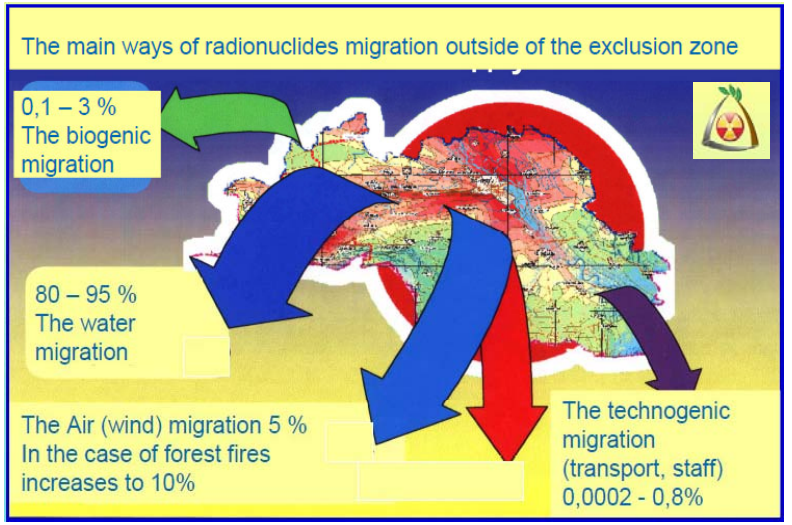
What kinds of satellite observations and analysis have been really useful for the management of the Chernobyl exclusive zone?

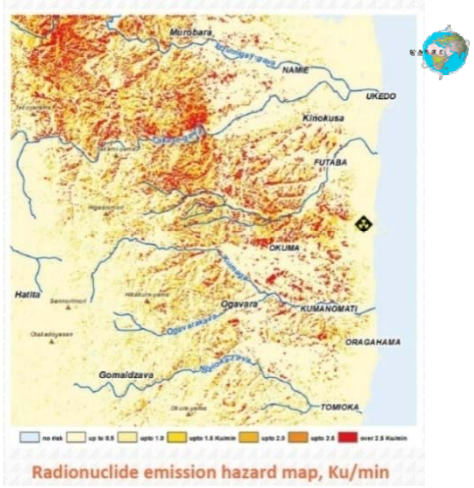
Basic important lessons learning:

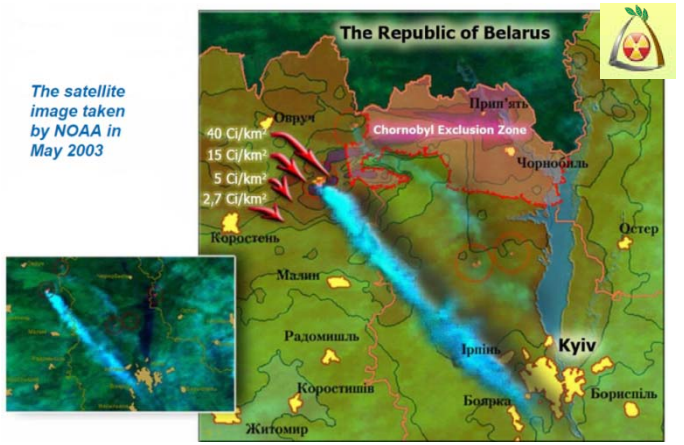
1. It is very important to prevent the radionuclide migration outside of the exclusive zone.
   80 to 95% of the total migration around Chernobyl is by water and 5% by air (to 10% by forest fires.)

2. The barrier function of the exclusive zone is important for the protection of populated areas. We should reduce the risk of forest fires and the risk of huge emissions of radionuclide in rivers during floods.

3. Satellite observations are useful for predicting floods and for implementing protective measures; identifying the vulnerable forest areas for fire such as dead wood; and modeling the situation in the region.







Preliminary Radionuclide Emission Hazard Map of Fukushima
– to be discussed at panel discussion on microsatellite applications on 21st

What kinds of satellite observations and analysis have been really useful for the government management of the exclusive zone?

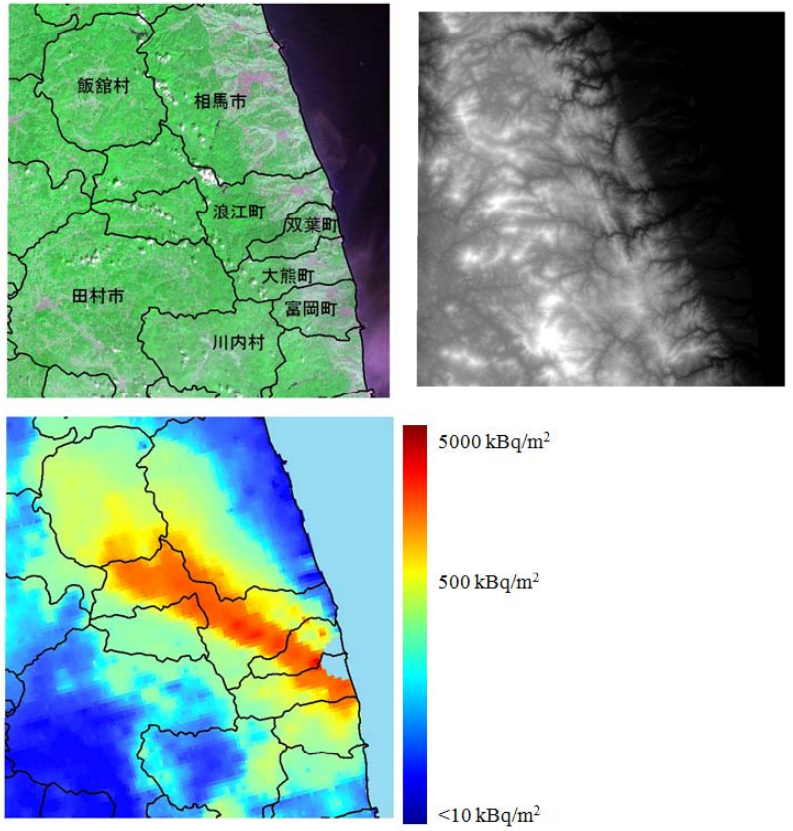
Important advices after Fukushima field survey:

1. Terrain of Fukushima is not flat and is much more complicated than that of Chernobyl. The contamination levels of forest in the mountain areas are not well monitored yet.
2. The radionuclide will migrate contentiously from the mountain areas to flat areas by water (both surface and underground) even after decontamination of the flat areas.

→ *S&F data collection of radiation intensity from :*

- *Mountain areas*
- *Suspected migration pathways such as mountain streams*
- *Ocean*

With support of Ukrainian partners, the University of Tokyo is developing observation strategies for Fukushima.



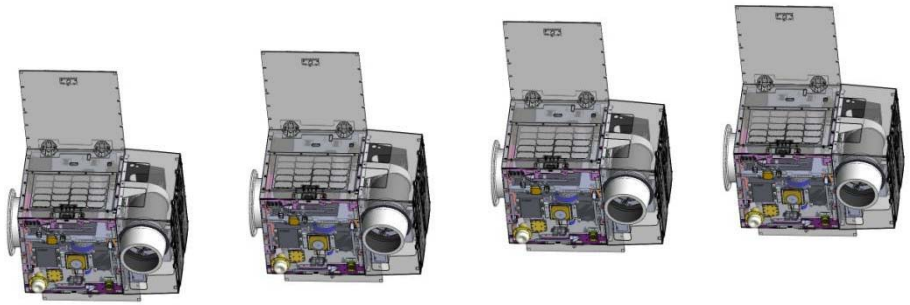
Top left: ASTER Image around Fukushima (2010/09/10)
Top right: Example of ASTER DEM
Bottom: Cs-134 by Aircraft monitoring (2012/12/28)

Schedule for Environment Monitoring of Fukushima and Chernobyl areas

2013	2014	2015	2016	2017--
Preparation phase ● Preparation of Satellites and Ground facility ● Learning Chernobyl Experience ● Field Survey ● Planning and Discussion ● Preliminary Join tAnalysis using existing Satellites	**Technical demonstration phase** ● Launch of Microsatellite Cluster ● Observation ● Joint Analysis ● Field Survey ● Start of preparation of follow-on dedicated satellites if government funding is allocated.	**Technical demonstration phase** ● Observation ● Analysis ● Field Survey ● Preparation of follow-on dedicated satellites if government funding is allocated.	**Transition to routine observation phase** ● Observation ● Analysis ● Field Survey ● Launch of follow-on dedicated satellites if government funding is allocated.	**Routine observation phase** if government funding is allocated. ● Observation ● Analysis ● Field Survey

Conclusion

- *Space segments and ground segments are almost ready and are waiting for launch in early 2014.*
- *The observation strategies are being developed with the support of Ukraine partners. These strategies, together with frequent observation by the constellation, would* ***support Government organizations to make informed, data-driven decisions****.*
- *We would like to propose to Government that it sponsor a* ***Follow-on low-cost microsatellite constellation dedicated to long-term monitoring of Fukushima****,*
  - Four Hodoyoshi4-like microsatellites with 2.5m GSD multispectral imagers and 5 year life
  - with a total cost less than 30MUS$ (1/1000 of estimated total cost for decontamination) including cluster launch.



Thank you very much for your attention.