Abstract: Himawari-8/9, a new generation of Japanese geostationary meteorological satellites, will carry state of art optical sensors of significantly higher radiometric, spectral and spatial resolution than hitherto available at geostationary orbit. When combined with fast revisit times (~10 minutes for full-disk and ~2.5 minutes for sectored region), they will provide a new level of capacity to identify and track rapidly changing weather phenomena such as tropical cyclones and contribute to the improvement of typhoon prediction.

SF 4.e.0 Introduction

On 7 October 2014 Japanese new generation geostationary meteorological satellite of Himawari-8 was successfully launched by H-IIA rocket from Tanegashima space center in Japan and settled at geostationary orbit on 16 October. Japan Meteorological Agency (JMA) will start its operation in the middle of 2015. Himawari-9 will be also launched in 2016 as an in-orbit standby and successor satellite of Himawari-8. Overview of Himawari-8/9 is shown in Fig. 1. Each of these satellites will be operational for a period of 7 years, so that the observation of Himawari-9 will continue to 2029 (Fig. 2). Himawari-8/9 will be employed by JMA ahead of other third generation meteorological satellites like Geostationary Operational Environmental Satellite (GOES)-R, which is a collaborative program between National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA), Meteosat Third Generation (MTG) of the EUropean organization for the exploitation of METeorological SATellites (EUMETSAT) and so on.

In this paper, general description of Himawari-8/9 will be presented. At first, their basic functions, specifications and grand segment will be found in section 2. Detailed explanation of new imager of Himawari-8/9 will be shown in section 3. In section 4, Himawari-8/9 imagery and data distribution or dissemination scheme from JMA will be found. Section 5 shows physical retrieval products from satellites observation for Tropical Cyclone (TC) analysis and prediction. In section 6, development plan for new products and application for Himawari-8/9 observation data will be discussed. Section 7 summarizes the paper.
Himawari-8/9 have identical specifications listed in Table 1. They are three-axis attitude-controlled satellites with total length of approximately 8 meters and mass of approximately 3,500 kg at launch. Both satellites will be located at 140.7 degrees east. Himawari-8/9 are equipped with highly improved Advanced Himawari Imagers (AHIs), which have capabilities comparable to that of the Advanced Baseline Imager (ABI) on board GOES-R (Schmit et al. 2005; Schmit et al. 2008). The description of AHI will be found in next section.
Table 1 Major specifications of Himawari-8/9

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitude control</td>
<td>3-axis stabilization</td>
</tr>
<tr>
<td>Size while in operation</td>
<td>Total length: approx. 8 m</td>
</tr>
<tr>
<td>Mass</td>
<td>Dry mass: approx. 1,300 kg</td>
</tr>
<tr>
<td></td>
<td>At launch: approx. 3,500 kg</td>
</tr>
<tr>
<td>Design lifetime</td>
<td>Meteorological mission: 8 years or longer</td>
</tr>
<tr>
<td></td>
<td>Satellite: 15 years or longer</td>
</tr>
<tr>
<td>Geostationary position</td>
<td>140.7 degrees east</td>
</tr>
<tr>
<td>Imager</td>
<td>Advanced Himawari Imager (AHI)</td>
</tr>
<tr>
<td>Space environment monitor</td>
<td>Space Environment Data Acquisition Monitor (SEDA)</td>
</tr>
<tr>
<td>Communications</td>
<td>1) AHI data transmission</td>
</tr>
<tr>
<td></td>
<td>Ka-band, 18.1 – 18.4 GHz (downlink)</td>
</tr>
<tr>
<td></td>
<td>2) Data Collection System (DCS)</td>
</tr>
<tr>
<td></td>
<td>Uplink from Data Collection Platforms (DCPs)</td>
</tr>
<tr>
<td></td>
<td>402.0 – 402.4 MHz (uplink)</td>
</tr>
<tr>
<td></td>
<td>Transmission to ground segments</td>
</tr>
<tr>
<td></td>
<td>Ka-band, 18.1 – 18.4 GHz (downlink)</td>
</tr>
<tr>
<td></td>
<td>3) Telemetry and command</td>
</tr>
<tr>
<td></td>
<td>Ku-band, 13.75 – 14.5 GHz (uplink)</td>
</tr>
<tr>
<td></td>
<td>12.2 – 12.75 GHz (downlink)</td>
</tr>
<tr>
<td>Contractor</td>
<td>Mitsubishi Electric Corporation</td>
</tr>
<tr>
<td>Launch vehicle</td>
<td>H-IIA rocket</td>
</tr>
</tbody>
</table>

Himawari-8/9 satellites and ground equipment for them are operated by a special purpose company named “Himawari Operation Enterprise Corporation (HOPE)”. HOPE operates the control of Himawari-8/9, receives data derived from AHI and Data Collection Platform (DCP), and transmits them to JMA. JMA processes those data and disseminates products to users. Figure 3 shows the scheme of Himawari-8/9 ground segment.

Figure 3: overview of ground segment for Himawari-8/9
Ku-band is used for telemetry, tracking and command of Himawari-8/9 satellite and Ka-band is used for the down-link of the data from AHI on Himawari-8/9 satellites. These Ku/Ka-bands tend to be subject to the influence of rain attenuation. To minimize the negative effect on data, the site diversity was introduced. The antenna sites with approximately 800 km distance were established in Kanto region (primary station) and Hokkaido region (secondary station) in Japan. The data centers were also located in the same area as those of antenna sites to process the received data.

In each antenna sites, there are transmitting and receiving equipment with two antennas of 9 meters in diameter. In the data centers, equipment of satellite control and AHI data processing were installed. AHI data received at antenna sites are transmitted to data centers. AHI data are processed to level 1a data (“Himawari radiometric data”; raw data with calibration and navigation parameter attached). These processed data in data centers are transmitted to JMA Meteorological Satellite Center (MSC) and JMA Osaka Regional Headquarters (hereafter called as “Osaka”).

The computer systems for exclusive use for processing the data transmitted from the data centers were installed in MSC and Osaka. MSC receives Himawari radiometric data from both data centers and those data are interpolated, compared, and selected. After that, level 1b data of “Himawari Standard Data” (HSD) and High Rate Information Transmission (HRIT) files are produced and disseminated to users.

On the other hand, Osaka receives data only from the secondary data center. When MSC system becomes dysfunctional because of regional infrastructure system malfunctions by natural disaster and etc., satellite data and products will be distributed from Osaka.

**SF 4.e.3 AHI instrument**

AHIs on board Himawari-8/9 are greatly improved in terms of the number of band, spatial resolution and temporal frequency comparing with JMA current geostationary meteorological satellite series of Multi-functional Transport SAtellites’ (MTSATs) imagers. AHIs have 16 observation bands (3 for visible, 3 for near-infrared and 10 for infrared) whereas the MTSAT series’ imagers have 5 bands. Table 2 shows the list of the Himawari-8/AHI and MTSAT-2/Imager bands with each wavelength.

<table>
<thead>
<tr>
<th>Band #</th>
<th>Wavelength (µm)</th>
<th>Spatial resolution (km)</th>
<th>Band Wavelength (µm)</th>
<th>Spatial resolution (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#1</td>
<td>0.46</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>0.51</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td>0.64</td>
<td>0.5</td>
<td>VIS 0.68</td>
<td>1</td>
</tr>
<tr>
<td>Near-Infrared</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>0.86</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td>1.6</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#6</td>
<td>2.3</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infrared</td>
<td>#7 3.9</td>
<td>IR4 3.7</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
The spatial resolutions of AHIs at sub-satellite point are also listed in the table. The highest spatial resolution of AHIs is 0.5 km for band #3 in visible wavelength. The spatial resolution of other visible bands and band #4 in near-infrared wavelength is 1 km. Other near-infrared bands and all infrared bands have the spatial resolution of 2 km. The spatial resolutions of visible and infrared bands of AHIs are twice of those of MTSAT-2/Imager.

Each band of AHI has its own characters as follows. True-color image from a combination of the three visible bands (blue: #1; green: #2; red: #3) looks as it was seen by the human eye. Near-InfraRed (NIR) bands #4-6 will provide information of cloud physical parameters such as water/ice phase, particles size, optical thickness and etc. The short wave infrared band #7 has heritage from MTSAT series. This band will be used to detect low level cloud, fog, wild fire and etc. Three bands #8-10 in the water vapor absorption band are available whereas only one band for the MTSAT series. The water vapor bands are sensitive to the middle to upper atmospheric humidity and the difference of the sensitivity between the bands will provide the information of humidity vertical profiles. The band #11 will be used for the thin ice cloud detection in conjunction with the other atmospheric window bands. The band #12, which is in the ozone absorption band, will be used for monitoring of stratospheric ozone and indirectly potential vorticity. There are three bands of #13-15 in the 10-12 µm atmospheric window whereas MTSAT series have 2 bands (so-called 'split window'). These bands will be used for identification of ice crystal/water, lower water vapor, volcanic ash, sea surface temperature and etc. Atmospheric window band has been equipped by most meteorological satellites and mainly used for operational weather forecast and analysis. The band #16, which is in the CO2 absorption band, will be used for cloud top height assignment and estimation of thin cirrus opacity.

Figure 4 shows AHI observation areas and frequencies in each 10-minute period which is called a timeline. AHI scans five areas: Full Disk, Japan Area (Regions 1 and 2), Target Area (Region 3) and two Landmark Areas (Regions 4 and 5). While the scan ranges for Full Disk and Japan Area are preliminarily fixed, those for Target Area and Landmark Areas are flexible to enable prompt response to meteorological conditions such as TC. At the beginning of Himawari-8 operation,
both of Landmark Area data are used only for navigation and calibration (moon observation), and are not intended for use as satellite products. In future, JMA plans to use one of Landmark Areas (Region 5) for observation of phenomena such as rapidly developing cumulonimbus cloud and to provide the resulting data to users. On a timeline, AHI scans Full Disk once, Japan Area and Target Area four times, and each Landmark Areas twenty times. It means that AHI takes Full Disk with every 10 minutes, Japan Area and Target Area with every 2.5 minutes, and each Landmark Areas with every 30 seconds. In Himawari-8/9’s baseline observation, the timeline is repeated every 10 minutes except in their housekeeping operation.

Figure 4: AHI observation areas and frequencies on a timeline of 10 minutes.

SF 4.e.4 Level-1b products and data distribution/dissemination

In JMA, Satellite-derived level-1a data of Himawari radiometric data are processed to create HSD as level-1b product in “Himawari Standard Format (HSF)”. HSD are master data for all Himawari-8/9 products. The details of HSD and HSF are shown in the MSC website of http://www.data.jma.go.jp/mscweb/en/himawari89/space_segment/spsg_sample.html. Imageries of Himawari-8/9 in other data formats such as HRIT, Low Rate Information Transmission (LRIT), Portable Network Graphics (PNG) and Network Common Data Form (NetCDF) are processed from HSD, and disseminated from JMA via multiple paths.

Imagery from JMA current operational satellite, MTSAT-2, is provided via MTSAT-1R direct dissemination through the L-band frequency HRIT and LRIT services. Most National Meteorological and Hydrological Services (NMHSs) in the East Asia and Western Pacific regions receive this imagery using L-band antennas and receivers, and process it with dedicated systems. Himawari-8/9 do not carry any equipment for direct dissemination. Instead, all imageries derived from the satellites are distributed to NMHSs via an Internet cloud service. JMA will also start the HimawariCast service, by which primary sets of imagery are disseminated to users via a communication satellite using Digital Video Broadcasting - Satellite - Second Generation (DVB-S2) technology. In this section, distribution/dissemination paths prepared by JMA will be shown as below.
SF 4.e.4.1 Internet cloud service

To distribute the enormous volumes of Himawari-8/9 imagery, JMA will establish an Internet cloud service mainly for NMHSs in the East Asia and Western Pacific regions. Table 3 shows the tentative data set to be distributed via the cloud service. HSD are provided as the core data of this service with 16 bands and the finest spatial resolution. The true-color images as mentioned at section 4 are provided in PNG format. For rapid scanning observation, imagery in NetCDF are also created and distributed. Each NMHS is able to access the cloud and get data using an HTTP 1.1 client such as a Web browser or Wget command. It is important to note that an Internet connection with a speed of at least 25 Mbps is required to download all HSD. These data are separately created for each band and divided into 10 segments from north to south so that NMHSs can select only the files necessary for their operation. JMA plans to start test operation of the Internet cloud service in first quarter of 2015 with distribution of Himawari-8 in-orbit-test imagery.

Some Japanese universities and research organizations are now planning to get Himawari-8/9 data from the internet cloud service and open them for research purpose. These organizations are not internal ones of JMA. Their services are based on the voluntary work and conducted on best-effort.

Table 3: The tentative data set to be distributed via the Internet cloud service

<table>
<thead>
<tr>
<th>Format</th>
<th>Observation area</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Himawari Standard Data</td>
<td>Full disk</td>
<td>- Full disk: every 10 minutes</td>
</tr>
<tr>
<td></td>
<td>Target area</td>
<td>- Target area: every 2.5 minutes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 16 bands</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Finest-spatial-resolution data</td>
</tr>
<tr>
<td>Portable Network Graphics (PNG)</td>
<td>Full disk</td>
<td>- True-color images (composites of 3 visible bands)</td>
</tr>
<tr>
<td></td>
<td>Target area</td>
<td>- Full disk: every 10 minutes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Target area: every 2.5 minutes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Same spatial resolution as Himawari Standard Data</td>
</tr>
<tr>
<td>Network Common Data Form (NetCDF)</td>
<td>Target area</td>
<td>- Every 2.5 minutes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 16 bands</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Same spatial resolution as Himawari Standard Data</td>
</tr>
</tbody>
</table>

SF 4.e.4.2 HimawariCast service

The Internet cloud service requires high-speed Internet access, whereas the HimawariCast service is suitable for users with limited Internet access. Table 4 shows the tentative data set to be disseminated via communication satellite. HRIT files represent the core data of the service, and LRIT files are also included to support current LRIT service users. The dissemination further includes meteorological data other than Himawari imagery in SATellite Animation and Interactive Diagnosis (SATAID) format. SATAID was developed by JMA, and is a set of software to display and analyze satellite images with other meteorological data. The details of SATAID will be found in the website of http://www.data.jma.go.jp/mscweb/en/VRL/sataid/index.html. The sample image of SATAID viewer is shown in Fig. 5. SATAID visualization software enables the
superimposition of various data and products, such as Numerical Weather Prediction (NWP) information, in-situ observation data and so on, onto satellite imagery. SATAID is widely used by NMHSs in the East Asia and Western Pacific regions as an operational tool for daily weather analysis and forecasting due to its usefulness and convenience.

The HimawariCast receiving and processing system includes a C-band antenna system, a Low Noise Block converter (LNB), a DVB-S2 receiver and a desktop computer with data casting client software and visualization software. More information on the system is found in the website of http://www.data.jma.go.jp/mscweb/en/himawari89/himawari_cast/himawari_cast.html.

JMA will start the HimawariCast service from January 2015 when MTSAT-2 is still in operation. MTSAT-2 imagery is disseminated through this service in parallel with direct dissemination via MTSAT-1R until Himawari-8 becomes operational in the middle of 2015. Himawari-8 data imagery is thereafter disseminated operationally via the HimawariCast service.

Table 4: The tentative data set to be disseminated via communication satellite

<table>
<thead>
<tr>
<th>Data type</th>
<th>Format</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Himawari imagery (full disk)</td>
<td>HRIT files¹</td>
<td>- Format compatible with the current MTSAT series HRIT and LRIT services</td>
</tr>
<tr>
<td></td>
<td>LRIT files</td>
<td>- Every 10 minutes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- HRIT: 5 bands (VIS: 1; IR: 4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LRIT: 3 bands (VIS: 1; IR: 2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Coarser spatial resolution than Himawari standard data</td>
</tr>
<tr>
<td>Numerical weather prediction products (GPV)</td>
<td>SATAID format</td>
<td>- JMA Global Model (GSM) products</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Every 6 hours</td>
</tr>
<tr>
<td>In-situ observations (surface stations, ships,</td>
<td>SATAID format</td>
<td>- Observation data collected from the East Asia and Western Pacific</td>
</tr>
<tr>
<td>radiosondes)</td>
<td></td>
<td>regions</td>
</tr>
<tr>
<td>ASCAT ocean surface wind (EUMETSAT)</td>
<td>SATAID format</td>
<td>- Originally provided by the EUMETSAT Ocean and Sea Ice Satellite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Application Facility (OSI SAF) and converted into SATAID format by JMA</td>
</tr>
</tbody>
</table>
Figure 5: Sample image of SATAID viewer. Satellite infrared imagery (black and white) is visualized with contours of surface pressure (yellow contours), surface air temperature (red contours) and wind barbs (blue) of NWP.

SF 4.e.4.3 JMA website

For general public use, JMA provides current MTSAT-2 imagery in PNG format on its website. In order to facilitate rapid downloading of essential imagery for meteorological services, the Agency also formulates various types of cut-out imagery in Joint Photographic Experts Group (JPEG) format on its website. JMA continues this service on the following websites even after Himawari-8 becomes its main operational satellite.

http://www.jma-net.go.jp/msc/indexe.html

SF 4.e.5 Level-2 products

The second generation geostationary meteorological satellites of MTSAT series' imagers have 5 observation bands (1 for visible and 4 for infrared). Using imageries from these bands, JMA has watched synoptic scale meteorological phenomena such as extratropical cyclones, baiu front activities, TCs and so on to prevent meteorological disasters.

The best practice of these efforts is the employment of Dvorak method to estimate the intensity of TCs (Dvorak 1975, 1984; Velden et al. 2006). Objective Dvorak Method was also developed by Velden et al. (1998) and Olander and Velden (2007). Dvorak method has been employed by the Regional Specialized Meteorological Centres (RSMCs) to analyze the intensity of TCs from satellite observations. In 2013, RSMC Tokyo has achieved the practical use of Objective Dvorak Method (Kishimoto et al. 2013). To prepare the data sets from new generation geostationary satellites such as Himawari-8/9 and GOES-R, Objective Dvorak Method have been updated (Goodman et al. 2012).

Level 2 physical products from geostationary meteorological satellites have also contributed to JMA tasks. For example, Clear Sky Radiance (CSR) and Atmospheric Motion Vector (AMV) products retrieved from MTSATs are indispensable sources for the initialization of NWP. As described in section 3, Himawari-8/9 will offer high observation potential, which will enable users to develop and improve a wide range of these physical products. Current satellite products such as cloud property information, CSR and AMV will be improved by
using AHI data. The followings give brief introductions to these basic meteorological products from Himawari-8/9 AHI developed by JMA.

SF 4.e.5.1 Fundamental cloud product

Cloud property information is the most essential meteorological product derived from satellite observations not only because it is used for weather analysis but also because it is applied to retrieval of other products (e.g. CSR and AMV). Taking into account its importance, JMA is currently developing two types of cloud products from Himawari-8/9. One is based on the “empirical” approach, and the other adapts the “physical (1D-Var)” approach. In this report, the cloud product via former way will be shown as below.

Fundamental cloud product, which is retrieved by empirical approach, provides cloud mask, cloud top height, cloud type and phase for each pixel of the Himawari-8/9 infrared bands (2 km at the sub-satellite point). The algorithm is based on the methods developed by the Nowcasting Satellite Application Facility (Meteo-France 2012). It uses threshold technique with brightness temperature and reflectivity for cloud mask and cloud type/phase retrieval. It also uses local radiative center and threshold tuning method developed by NOAA/ National Environmental Satellite, Data, and Information Service (NESDIS) (Heidinger 2011). Interpolation, intercept (Szejwach 1982) and radiance rationing method (Menzel et al. 1983) are applied to cloud height assignment. Fundamental cloud product algorithm uses radiative transfer calculation results obtained from the numerical prediction data to determine thresholds for clear sky radiance from infrared channels. Prototype product was made by using Meteosat Second Generation (MSG)/Spinning Enhanced Visible and InfraRed Imager (SEVIRI) data (Schmetz et al. 2002).

SF 4.e.5.2 CSR

The CSR product provides area averaged radiances and brightness temperatures for cloud-free pixels (Uesawa 2009). NWP centers will use Himawari-8/9 CSR product in their operational assimilation systems as primary data source. Himawari-8/9 CSR is calculated for each 16 x 16 infrared pixel boxes that correspond to approximately 32 x 32 km² resolutions at the sub-satellite point for global assimilation system. Whether a pixel is clear or cloudy is determined from fundamental cloud product. In addition to the ordinary clear pixels provided from fundamental cloud product, when the contribution of cloud top emission to total radiance is negligible in one pixel, such “cloudy” pixel can be regarded as a “clear” pixel for AHI bands with strong absorption (e.g. water vapor bands). These CSR products will be provided in Binary Universal Form for data Representation (BUFR) via Global Telecommunication System (GTS).

SF 4.e.5.3 AMV

AMV is one of the most important meteorological products retrieved from meteorological satellites for NWP. For example, Bormann et al. (2012) shows that AMVs from satellites have positive impact on forecast skill in the European Centre for Medium-Range Weather Forecasts (ECMWF) data assimilation system. In JMA, a new algorithm has been developed for Himawari-8/9 AMV (Shimoji 2014). This algorithm uses optimal estimation method so that information of satellite data
is fully exploited to retrieve AMV. Improvement from the current operational algorithm (Oyama 2010) will result in the computation of wind vectors with high spatial resolution by tracking smaller cloud pattern. Figure 6 shows comparison results of AMVs from MTSAT observation data between by the current operational algorithm and by the newly developed algorithm for Himawari-8/9. In the figure, wind vectors by new algorithm with high quality (Quality Indicator (QI) > 80) (Holmlund et al. 1998) are found over wide areas where those retrieved by current operational one cannot be found. Same as CSR, AMV product will be also provided in BUFR via GTS.

![Figure 6: MTSAT IR wind vectors (QI > 80) retrieved by the current operational algorithm (a) and with the newly developed algorithm for Himawari-8/9 (b) at 00 UTC on 2 March 2014. Warm colors correspond to low-level wind and cold colors to high-level wind.](image)

For the research purpose, JMA specially produced Rapid Scan AMVs (RS-AMVs) from MTSAT-1R images near Japan islands with every 10 minutes in October 2013. In this period, six typhoons (SEPAT, FITOW, DANAS, WIPHA, FRANCISCO and LEKIMA) passed around Japan (Fig. 7). Observing System Experiments (OSEs) were conducted to evaluate the impact of MTSAT-1R RS-AMVs on the typhoon forecast using operational global NWP system as of 1 November 2013 (Yamashita 2014). In the OSEs, the super-observation procedure was adopted to average RS-AMVs with 100 km intervals in hourly time window. Results of the OSEs showed that mean positional errors of the typhoon track
forecasts were reduced about 8% from 30- to 84-hour forecasts (Fig. 8). From these results, it is expected that RS-AMVs from Himawari-8/9 will improve the accuracy of TC track forecast.

Figure 7: 6 typhoons passed around Japan from 2 October to 16 October 2013. Blue lines surrounding Japan represent a region of rapid scan observation from 120°E to 150°E and from 20°N to 45°N.

Figure 8: Average track forecast errors of six typhoons from 2 October to 16 October 2013. The red line is for 100km Super-observation experiment values, the blue line is for RTN values, the red dots are sample data numbers, and the error bars represent a 95% confidence interval.

SF 4.e.5.4 Rapidly Developing Cumulus Area product

Himawari-8/9 will make observations over Japan at 2.5-minute intervals. The advent of frequent observations from space has the potential to improve severe weather analysis and forecast. Rapidly Developing Cumulus Area (RDCA) product has been developed for monitoring rapidly developing convective cloud by using rapid-scan (5-minute interval) observations of MTSAT-1R around Japan during the daytime (00 to 09 UTC) in summer (June to September) (Sumida et al.)
RDCA product indicates highly potential areas for active convection and heavy rainfall. The algorithm of the product detects rapid changes in cloud conditions (e.g., sudden genesis and evolution of cumulonimbus cloud) based on an empirical approach by matching up satellite observation with ground-based lightning remote sensing observation. Figure 9 shows an example of RDCA retrieved from MTSAT-1R observation data at 08:45 UTC on 11 July 2011. The green region on the image shows rapidly developing cumulus area and the red region shows cumulonimbus area. Those areas almost corresponded to severe convective region estimated from ground remote sensing results such as radars and lightning detection network in Japan. The algorithm of this product will be modified with Japan Area observation every 2.5 minutes of Himawari-8/9. After this improvement RDCA product will be provided at all times in every season. There is a big potential that TC intensity can be estimated by the application of RDCA product.

Figure 9: Sample imagery of RDCA product at 08:45 UTC on 11 July 2011. RDCA is colored with green, Cumulonimbus area is colored with red and unknown area covered by middle or low level cloud is colored with aqua. The nighttime area where solar zenith angle is greater than 75 degrees is overwritten with purple, and RDCA cannot be detected in the nighttime area.

SF 4.e.5.5 RGB composite image

As Himawari-8/9 have 16 bands and the number of combination of these bands is so many, it will be difficult for forecasters and analysts to interrupt the combined AHI imageries in one glance. It is needed to provide them satellite images to be read easily as a satellite operator. Red, Green and Blue (RGB) composite images are suitable for this purpose. For the user preparedness of GOES-R, Goodman et al. (2012) shows several RGB composite images will be useful for TC analysis. The images from Himawari-8/9 AHI will be provided by JMA for NMHSs in Southeast Asia and South Pacific islands via the MSC website. These images will be produced using the recipes recommended at the RGB Composite Satellite Imagery Workshop which were based on the observational results from MSG/SEVIRI with 12 bands (WMO and EUMETSAT 2007). Same as the MTSAT RGB composite images on the MSC website (Fig. 10), Himawari-8/9 RGB images will contribute to World Meteorological Organization (WMO) Commission for Basic Systems (CBS) Severe Weather Forecasting.
Demonstration Project (SWFDP) and Severe Weather Forecasting and Disaster risk reduction Demonstration Project (SWFDDP).

Figure 10: MSC Website for providing RGB composite images from MTSAT to users in Southeast Asia. Himawari-8/9 RGBs will be provided in the same way.

SF 4.e.6 Future plan

In previous section, some basic physical products to be retrieved from Himawari-8/9 observation data by JMA were described. Each product will have its own improvement from the current one developed for MTSAT series data. However, there is still big room to improve or sometimes newly develop the physical products or the satellite applications by using the observation data from Himawari-8/9. As shown already, Himawari-8/9 have huge capability of temporal and spatial high resolution observation with 16 bands. To utilize the observation data fully, it will be better to keep some key concepts in mind such as conjunction with numerical model, advanced assimilation, application to frontier theme and combination of multi observation platforms. Because no one has experience to handle the data sets from next generation geostationary meteorological satellites, innovative ideas based these concepts are needed to bridge a gap between observation data supply and usage of them.

AHI can make observations with faster imaging and higher spatial resolution than MTSAT/Imager. The detailed cloud information inferred from every 10-minutes full disk images or every 2.5 minutes Japan area images of AHI will
show the lifecycle of cloud including its genesis, evolution and decay more clearly than ever before. For example, Nakajima et al. (2010a, 2010b) suggest that time variation of cloud evolution could be chased by using the observation results from AHI band #5-7, which belong to near-infrared or infrared wavelength. The cloud droplet size can be estimated from the difference of effective vertical weighting function between these bands. Traditional radar meteorology, which studies atmospheric science using radar observation results, is sort of “mesoscale rain meteorology”. AHI of Himawari-8/9 will open the door to new era of “mesoscale cloud meteorology”. In other words, “mesoscale satellite meteorology” will be born from these next generation geostationary meteorological satellites. As a next step of this satellite revolution, the new research theme which deals with everything from the genesis of cloud particle to the decay of rain fall in an integrated manner with a combination of radar and satellite observations will be raised.

In this section, some future products and applications for TC analysis and prediction based on the key concepts mentioned above from new generation geostationary satellites will be introduced.

SF 4.e.6.1 AMVs for Nowcasting

AMVs derived from short-interval images are considered useful for capturing short-lived phenomena such as rapidly developing cumulus cloud or rapidly deforming TC cloud systems. Currently, the Advanced SCATterometer (ASCAT) surface wind data are utilized as a main ancillary resource in JMA typhoon analysis, especially for estimation of gale force wind areas over data-sparse sea regions. However, as ASCAT coverage is temporally sparse (ASCAT carried by Metop satellites observes the same points twice a day), data-sparse regions need to be compensated for by other observations. As mentioned in section 5, MTSAT-1R had special rapid-scan (5-minute interval) observations around Japan during the daytime in summer. Figure 11 shows an example of comparison between operational MTSAT-2 hourly AMVs and MTSAT-1R RS-AMVs with every 5 minutes based on visible images in the vicinity of TC. It is easily understood that number of RS-AMV was bigger than that of hourly AMVs. The ability of rapid-scan images to capture short-lived cloud systems within TC supports their use for such compensation in data-sparse areas around TCs.

Figure 11: MTSAT-2 hourly AMV (left, blue barbs) and MTSAT-1R rapid-scan AMV (right, yellow barbs) based on visible images in the vicinity of Typhoon Ma-on at 00 UTC on 23 July 2011.
JMA also conducted a study to compare ASCAT wind and AMV data from rapid-scan visible imagery covering the vicinity of a TC to validate the use of RS-AMVs in TC analysis. Figure 12 shows the comparison results between RS-AMVs from visible imagery and ASCAT wind data from around the vicinity of Typhoon Ma-on in 2011. Wind speed comparison shows close correspondence, but the mean speed of ASCAT winds is about 0.8 times that of RS-AMVs up to 15 m/s. Wind direction differences are small compared to speed differences, but ASCAT winds are directed about 10 degrees inward to the TC center with RS-AMV data as a reference. These results indicate a close correlation between sea-surface winds and AMVs, as suggested by previous work involving the use of sea-surface wind data from in-situ observations (e.g., Ohshima et al. 1991; Dunion and Velden 2002). On the other hand, the wind speed of RS-AMVs is bigger than that of ASCAT winds in the high-speed region. This bias requires further investigation. It is expected that operational Himawari-8/9 every 10 minutes AMVs will provide almost similar results as MTSAT-1R RS-AMVs.

![Figure 12: Scatter plots of MTSAT-1R rapid scan wind from visible imageries and ASCAT wind data. (Left) Wind speed. (Right) Wind direction. The comparison period is from 17 to 23 July 2011, which is roughly corresponding to the period when Typhoon Ma-on was located within the rapid-scan area of MTSAT-1R.](image)

SF 4.e.6.2 Analysis of upper-tropospheric flows in TC using AMVs

Rapid-scan imageries from geostationary satellites obtained at intervals less than about 10 minutes enable to track clouds even in TC where the direction of cloud motion abruptly changes and vigorous convections occur. The upper-tropospheric AMVs, which were computed by tracking upper-tropospheric clouds and/or water vapor pattern from MTSAT-1R rapid-scan imageries, were applied to analysis of wind field in TCs (Fig. 13). The analyses of several TCs including Typhoon Roke in 2011 revealed that both tangential and radial wind components of the AMVs, i.e., the cyclonic circulation and horizontal divergence in the upper troposphere near the TC center, increased at the rapid intensification stage of the TCs. This result indicates that the AMVs reflected the intensification of the primary and secondary circulations of the TCs during the TC intensification. It is expected that studies using upper-tropospheric AMVs from Himawari-8/9 for TCs will
contribute to understanding of TC intensification processes and diagnosis of TC intensity change.

Figure 13: AMVs derived from WV imageries of MTSAT-1R rapid-scan observations with every 5 minutes for Typhoon Roke at 08:14 UTC on 19 September 2011. The background is WV image for the AMV retrieval.

SF 4.e.6.3 Targeted observation

As mentioned already in section 3, Himawari-8/9 imager of AHI has capability of flexible observation for Target Area with every 2.5 minutes and Landmark Areas with every 30 seconds. By using these functions, targeted observation will become realized. Targeted observation is an enhancement of operational observation network to be assimilated into NWP. Additional observations are installed into the sensitivity regions estimated from the ensemble forecasts where these additional observation data are effective to improve the prediction results. These ideas were implemented in many field experiments, especially in The Observing System Research and Predictability Experiment (THORPEX) (Majumder et al. 2011). THORPEX - Pacific Asian Regional Campaign (T-PARC) was one of the sub-programs of THORPEX. JMA also joined this experiment in 2008 and executed special observations such as dropsonde observations in cooperation with German research aircraft of Falcon, enhanced upper soundings by two research vessels and four automatic upper-sounding stations, and MTSAT-2 rapid scan operations (Nakazawa et al. 2010). The effectiveness of assimilating AMVs from MTSAT rapid scan observation data in T-PARC for NWP was validated by Yamashita (2010) and Wu et al. (2014). The flexible observations by Himawari-8/9 have big potential to be an operational tool for targeted observation. As a first step, it is expected to start an experimental application of these functions of AHI with the sensitivity analysis by ensemble predictions for the innovation of NWP.
SF 4.e.7 Conclusions

As described in this paper, new generation geostationary satellite platforms such as Himawari-8/9 carry optical sensors of significantly higher radiometric, spectral and spatial resolution than hitherto available at geostationary orbit. When combined with fast revisit times (~10 minutes), they will provide revolutionary capability to identify and track quickly-evolving events, and allow the development of new surface and atmospheric monitoring and mapping applications where a high temporal frequency and near real-time image supply are essential. JMA will process the raw data of Himawari-8/9 with quality control, create HSD, imageries and physical products, and use them for NWP, severe weather watching and the environment monitoring. Level-1b data are also distributed/disseminated to the external users via multi path from JMA such as internet cloud service, HimawariCast service and so on.

Himawari-8/9 will provide Full Disk observation with every 10 minutes by default. In the near future, such high-frequency full disk scanning will be a normal measure all over the world for supporting emergency situations, so that it is important to develop the usage of high frequency data for disaster risk reduction. It is also important to promote Himawari-8/9 data utilization in East Asia and the Western Pacific within the framework of WMO and Coordination Group for Meteorological Satellites (CGMS) in cooperation with RSMCs. For the utilization of these data in emergency cases, it is needed to clear the requirements in each NMHSs. Through the wide application in multi aspects of meteorological, hydrological and climate operation of the countries in these areas, many problems will be newly raised. By solving these problems, more effective usage of Himawari-8/9 data will be developed. JMA would like to continue these activities to contribute to the world as a satellite operator and one of NMHSs.

SF 4.e.8 Recommendations

To operational community

That satellite operators provide adequate technical guidance, and training particularly for developing countries in cooperation with RSCMs/TCWCs, for the smooth transition of the operational community to the next generation geostationary meteorological satellite.

To research community

That the research community, in cooperation with the operational community, explores new techniques to utilize next generation geostationary meteorological satellites data for operational TC analysis and forecasts. The research progress will be compiled and reported on at the next IWTC.

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Acronyms used in the report:

ABI          Advanced Baseline Imager
AHI          Advanced Himawari Imager
AMV          Atmospheric Motion Vector
ASCAT        Advanced SCATterometer
BUFR         Binary Universal Form for data Representation
CBS          Commission for Basic Systems
CGMS         Coordination Group for Meteorological Satellites
CSR          Clear Sky Radiance
DCP          Data Collection Platform
DVB-S2       Digital Video Broadcasting – Satellite – Second Generation
ECMWF        European Centre for Medium-Range Weather Forecasts
EUMETSAT     European organization for the exploitation of METeorological SATellites
GOES         Geostationary Operational Environmental Satellite
GTS          Global Telecommunication System
HOPE         Himawari Operation Enterprise Corporation
HRIT         High Rate Information Transmission
HSD          Himawari Standard Data
HSF          Himawari Standard Format
JMA          Japan Meteorological Agency
JPEG         Joint Photographic Experts Group
LNB          Low Noise Block converter
LRIT         Low Rate Information Transmission
MSC          Meteorological Satellite Center
MSG          Meteosat Second Generation
MTG          Meteosat Third Generation
MTSAT        Multi-functional Transport SATellite
NASA         National Aeronautics and Space Administration
NESDIS       National Environmental Satellite, Data, and Information Service
NetCDF       Network Common Data Form
NIR          Near-InfraRed
NMHS         National Meteorological and Hydrological Service
NOAA         National Oceanic and Atmospheric Administration
NWP          Numerical Weather Prediction
OSE          Observing System Experiment
PFI          Private Finance Initiative
PNG          Portable Network Graphics
QI           Quality Indicator
RDCA         Rapidly Developing Cumulus Area
RGB          Red, Green and Blue
RS           Rapid-Scan
RSMC         Regional Specialized Meteorological Centre
SATAID       SATellite Animation and Interactive Diagnosis
SEVIRI       Spinning Enhanced Visible and Infrared Imager
SRF          Spectral Response Function
SWFDDP       Severe Weather Forecasting and Disaster risk reduction Demonstration Project
SWFDP        Severe Weather Forecasting Demonstration Project
TC           Tropical Cyclone
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