

Guidelines on Best Practices for Achieving User Readiness for New Satellite Systems

2024 edition

WEATHER CLIMATE WATER



WORLD
METEOROLOGICAL
ORGANIZATION

WMO-No. 1187

Guidelines on Best Practices for Achieving User Readiness for New Satellite Systems

2024 edition



WORLD
METEOROLOGICAL
ORGANIZATION

WMO-No. 1187

EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at <https://wmo.int/wmo-community/meteoterm>.

Readers who copy hyperlinks by selecting them in the text should be aware that additional spaces may appear immediately following <http://>, <https://>, <ftp://>, <mailto:>, and after slashes (/), dashes (-), periods (.) and unbroken sequences of characters (letters and numbers). These spaces should be removed from the pasted URL. The correct URL is displayed when hovering over the link or when clicking on the link and then copying it from the browser.

WMO-No. 1187

© World Meteorological Organization, 2024

The right of publication in print, electronic and any other form and in any language is reserved by WMO. Short extracts from WMO publications may be reproduced without authorization, provided that the complete source is clearly indicated. Editorial correspondence and requests to publish, reproduce or translate this publication in part or in whole should be addressed to:

Chair, Publications Board
World Meteorological Organization (WMO)
7 bis, avenue de la Paix
P.O. Box 2300
CH-1211 Geneva 2, Switzerland

Tel.: +41 (0) 22 730 84 03
Email: publications@wmo.int

ISBN 978-92-63-11187-6

NOTE

The designations employed in WMO publications and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of WMO concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The mention of specific companies or products does not imply that they are endorsed or recommended by WMO in preference to others of a similar nature which are not mentioned or advertised.

CONTENTS

	<i>Page</i>
REFERENCE USER-READINESS PROJECT	1
1. BACKGROUND	1
2. APPLICABILITY	2
3. DIALOGUE BETWEEN SPACE AGENCIES AND USERS	3
4. ACTIVITIES BY USERS TO ACHIEVE READINESS	3
4.1 Establishment of a user-readiness project	4
4.2 Budgeting and planning	4
4.3 Research and development	5
4.4 Data-handling development and testing	5
4.5 Data-processing development and testing	6
4.6 Contributions to calibration and validation	6
5. CAPACITY DEVELOPMENT	6
6. SATELLITE SYSTEM DEVELOPMENT	8
7. DELIVERABLES FROM SATELLITE DEVELOPMENT PROGRAMMES TO USER- READINESS PROJECTS	10
7.1 Instrument pre-launch calibration and characterization	10
7.2 Product specifications	11
7.3 Product guides	12
7.4 Data access mechanism specifications	12
7.5 Software tools, documentation, and test data	13
7.6 Operations plans and schedules	13
7.7 Data access during early mission phases	14
7.8 User notification and feedback	14
7.9 Training resources	14
7.10 Other deliverables	15
8. TIMELINE FOR THE REFERENCE USER-READINESS PROJECT	15

REFERENCE USER-READINESS PROJECT

1. BACKGROUND

The space-based component is an essential part of the WMO Integrated Global Observing System (WIGOS), as outlined in the [Vision for the WMO Integrated Global Observing System in 2040](#) (WMO-No. 1243). New generations of satellite systems will bring significant improvements to satellite-based products and services delivered by WMO Members provided that users can effectively reap their benefits. These new systems will provide users with new types of data, with overall data volumes that are one or more orders of magnitude higher than those of the previous generation. Integrating these new data types into their operational schemes will have major impacts on users' infrastructures, systems, applications and services and will require coordinated actions at the scientific, technical, financial, organizational and educational levels. To avoid any disruption to their operations during the transition to these new satellite systems and to ensure that they take advantage of the new capabilities of the new systems in a timely manner, it is essential that satellite data users be prepared to utilize the new types of data as effectively and as early as possible.

New generations of satellite systems contributing significantly to fulfilling the WIGOS vision have been or will be employed by China, India, Japan, the Republic of Korea, the Russian Federation, the United States of America and the European Union, in both geostationary Earth orbit (GEO) and low Earth orbit (LEO). It is anticipated that other nations may also start planning their satellite missions in the future.

In LEO, core satellite systems in early morning, mid-morning and afternoon Sun-synchronous orbits are now providing microwave (MW) and hyperspectral infrared (IR) sounding and medium resolution IR/visible (VIS) imaging, ultraviolet (UV) spectrometry, radio occultation, and scatterometry. In addition, a number of LEO satellites in Sun-synchronous and drifting orbits are becoming operational, providing observational capabilities for atmospheric composition, ocean observations, land surface observations and other observational domains.

The WMO Commission for Basic Systems Guidelines for Ensuring User Readiness for New Generation Satellites were adopted by the Commission for Basic Systems (CBS) at its fifteenth session ([Commission for Basic Systems – Fifteenth Session: Abridged Final Report with Resolutions and Recommendations](#) (WMO-No. 1101) – Annex I (Annex to Paragraph 4.2.36 of the General Summary)). They focus on user preparation for the new generation of meteorological satellites and urge the “Establishment by each concerned NMHS [(National Meteorological and Hydrological Service)] or other operational user organization, of a user-readiness project focused on the introduction of new satellite data streams into operations (to be initiated ~5 years prior to launch)”.

Against this background, in 2015, the World Meteorological Congress, at its seventeenth session, through Resolution 37 (Cg-17) – Preparation for new satellite systems ([Seventeenth World Meteorological Congress: Abridged Final Report with Resolutions](#) (WMO-No. 1157)), strongly recommended “to all concerned Members to set up user preparation projects in advance of the launches of new satellite systems, in accordance with the CBS Guidelines for ensuring user readiness for new generation satellites”.

One of the main constraints for the planning of a user-readiness project is the timely availability of the requirements, specifications, data and tools used in the development of the corresponding satellite system. It is therefore crucial that satellite development entities and operators provide detailed and up-to-date plans for their activities in order to support user-readiness projects.

For this reason, Resolution 37 (Cg-17) also welcomed the implementation of the Satellite User Readiness Navigator (SATURN), which at one time served as a one-stop portal for technical information from satellite operators concerning new satellite systems. This effort was aimed at supplementing satellite operator portals by creating a link between users and satellite operators

to address an important gap. Since 2015, satellite operators have worked towards improving the usability of their web pages to ensure that the process of preparing users for new satellite data starts early.

The WMO Space Programme has analysed how the typical cycle of satellite system development relates to user-readiness projects, and the outcome of this analysis is a summary of best practices and a generic project schedule (outlined in the [table](#)). The generic schedule indicates what information should be available to both satisfy the user preparation schedule and respect the constraints of satellite system development and when that information should be available relative to the planned satellite launch.

The WMO Commission for Basic Systems, at its sixteenth session, through Decision 4 (CBS-16) – Best Practices for Achieving User Readiness for New-Generation Meteorological Satellites (*Commission for Basic Systems – Sixteenth Session: Abridged Final Report with Resolutions, Decisions and Recommendations* (WMO-No. 1183)), endorsed as CBS guidance the *Guidelines on Best Practices for Achieving User Readiness for New Meteorological Satellites* (WMO-No. 1187), published in 2017.

The revision of this publication reflects lessons learned from the satellite systems that have become operational over the last 5–10 years (such as Himawari-8/9, the Geostationary Operational Environmental Satellite (GOES)-R series (GOES-R), GEO-Kompsat-2, FengYun-4 (FY-4), FengYun-3 (FY-3) and the Joint Polar Satellite System (JPSS)), novel types of LEO missions, the increasing role of commercial satellite data providers, as well as evolutions in user needs.

2. **APPLICABILITY**

The current publication presents, in an integrated manner, best practices for user-readiness projects carried out by user organizations (for example, NMHSs) as well as for satellite development programmes to support user readiness. They contain a list of deliverables, with the corresponding timelines, which should be made available to user-readiness projects by satellite development programmes.

The best practices described herein therefore apply to both user organizations (see [section 4](#)) and satellite operators (see [section 6](#)).

They apply to all satellite systems providing sustained observations in response to operational user needs but focus on satellite systems that provide data which are critical for operational Earth system predictions, severe weather event warnings and the protection of life and property. User organizations and satellite operators have a shared responsibility to ensure that satellite data can provide maximum value for critical application areas.

The present document focuses on the critical time frame from five years before to two years after satellite launch; this forms part of a continuous user engagement process that starts even before formal approval of the satellite programme and continues throughout its lifetime.

The present publication is primarily intended for members of the Coordination Group for Meteorological Satellites (CGMS) and WMO, but the broader user community can also benefit from the information herein when shaping user readiness projects in their institutions.

This document is a very important guidance for commercial satellite data providers, and both CGMS and WMO will strive to ensure that the practices herein are followed for user-readiness preparations for all essential data provision, especially for global numerical weather prediction (NWP) applications.

3. **DIALOGUE BETWEEN SPACE AGENCIES AND USERS**

As a foundation for all user-readiness activities for satellite programmes, it is important to establish a two-way dialogue between users and data providers early during satellite system development. This is to inform users of what they can expect from the new observations, as well as for users to plan their preparation activities and express what they require in order to efficiently and effectively use the new data. Areas that will benefit especially from such early dialogues include expected data characteristics, format definitions, dissemination routes, proxy data, embedded integration of subject matter experts, end-to-end testing, identifying research and development needs for data applications, training/education needs, as well as identifying “readiness blockers” that require addressing by the user or the provider.

Efficient practices to facilitate this dialogue include satellite user conferences, scientific advisory groups, proving ground initiatives, testbeds, and early adopter programmes which engage expert users and space programme developers. The National Oceanic and Atmospheric Administration (NOAA) proving ground initiatives for GOES-R and JPSS, and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) user preparation projects for Meteosat Third Generation (MTG) and EUMETSAT Polar System-Second Generation (EPS-SG) have proven to be very efficient in supporting user readiness.

User groups established through these activities can also play an important role in the early in-orbit evaluation of satellite data, including the early demonstration of new capabilities of data applications.

User engagement workshops can help identify key needs of user communities as well as recommended user requirements for future observations. Engagement with the wider user community through, for instance, the appropriate CGMS science working groups, is essential in order to ensure that users are informed about the new types of data and that user-preparation activities are targeted and efficient.

Two critical elements of the dialogue between users and data providers are the identification of development needs for data applications, and discussions on appropriate resourcing, taking into account the budget realities for both the satellite programmes and the users. User engagement that includes research and development and the academic sector can help identify major research and development areas related to the new data. This, in turn, will accelerate the development of new products and applications and will inform upgrades to the supporting infrastructure of both the satellite providers and the users. The return of investing in space programmes can be greatly enhanced if the necessary development needs are identified early and sufficiently resourced. Identifying commonalities between different satellite programmes (for example, for radiative transfer modelling and data processing) and the development of community tools through user networks such as the EUMETSAT Satellite Application Facilities can be very cost-effective in this respect.

The level of dialogue required depends on the degree of novelty of the instrument. More extensive dialogue is needed to establish user-readiness requirements for a system with completely new sensing capabilities.

4. **ACTIVITIES BY USERS TO ACHIEVE READINESS**

The activities described below should be performed by user organizations to achieve readiness for new-generation satellites.

4.1 **Establishment of a user-readiness project**

It is crucial that the planning of a user-readiness project start early. The present *Guidelines* assumes that users need to prepare for an entirely new generation of satellites, in which case, the user-readiness project needs to be defined five years prior to satellite launch. In particular, it is crucial, as early as possible, to:

- (a) Clearly define project outcomes and deliverables;
- (b) Establish clear responsibilities and accountabilities;
- (c) Ensure that an adequate budget is available for all activities;
- (d) Establish a clear go-live plan for the upgraded infrastructure and new services;
- (e) Develop communication networks between satellite operators, key managers, project stakeholders, and users.

The user-readiness project needs to address the following areas:

- (a) New capabilities, as well as improvements to existing capabilities;
- (b) Operational service provision continuity, including critical path analysis for transition;
- (c) Obtaining maximum benefits from existing assets and protecting investments;
- (d) Maximizing service value at all times during the transition;
- (e) Research and development opportunities that underpin or benefit the development of novel products and applications;
- (f) Ensuring that the transition of users to the new system takes place in a timely fashion.

The project must also include a detailed assessment of opportunities and risks. It may be opportune to embed the project activities within larger-scale activities aimed at upgrading the service and improving its resources.

During the execution of the project, special consideration must be given to:

- (a) The need for a dedicated project manager (overall accountability is important);
- (b) Maintaining contact with the satellite operator for up-to-date information;
- (c) Maintaining regular communication between key managers and project stakeholders (to maintain momentum and counter misinformation);
- (d) Monitoring key project milestones with a view to escalating activities when necessary;
- (e) Ensuring that management support and buy-in is available when needed;
- (f) Managing expectations regarding the availability of new products.

4.2 **Budgeting and planning**

Budgeting and planning are of paramount importance and need to start early. A new-generation satellite system can be, in some cases, the driver of significant infrastructure upgrades and increased performance requirements in terms of data acquisition, storage and networks; as such, users should be made aware of the system many years in advance of the satellite launch so that

they can incorporate the necessary upgrades into their long-term evolution and investment plans. Schedule margins and other provisions should be realistic in order to avoid potential difficulties, due, for example, to launch delays.

A main objective for a user organization is to protect the investment made in existing operational programmes and to understand early where additional investments are necessary or unavoidable to achieve readiness for the new satellite system. It is therefore crucial for users to receive information about investment drivers as early as possible for budgeting and planning purposes.

4.3 **Research and development**

Research and development needs should be identified early in the preparation phase in dialogue with the data providers. In this context, “research and development” refers to the phase of activities that prepares users for the application of new-generation satellite data. This typically includes the development of NWP data assimilation methods using the new-generation satellite data where needed or the development of new or specially tailored products for specific application areas, for instance, by centres such as the EUMETSAT Satellite Application Facilities. These activities usually include computationally efficient tools to simulate the new observations, an analysis of the effects of instrument spectral response functions (SRFs), field of view (FOV), and so forth. Where possible, the use of common community software is advisable (for example, Radiative Transfer for the Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder (TOV) (RTTOV) software, Community Radiative Transfer Model (CRTM) software) to ensure efficient and consistent developments.

Planning such activities depends to a large extent on the degree of novelty of the instrument. For an upgraded version of an existing instrument series, the lead times can be shortened considerably, and some steps (for example, simulated data) can be dropped completely. In contrast, in the case of totally new instruments, an in-depth analysis of the specific development requirements is needed, taking into account the accuracy of forward-modelling tools, expected data volumes, and other processing needs. For instance, if an instrument measures in a spectral region not previously covered by other instruments, research into the spectroscopy for that region may be needed. Alternatively, if an instrument will provide a step-change in the amount of data, efficient methods of representing the information may need to be developed. To enable such research, a first-guess spectral response function may be useful as early as four years before the launch date; for this spectral response function, simulated data would be very useful. For observations using a completely new measurement method, entirely new forward-modelling tools may need to be developed to enable quantitative exploitation of the data, which may require substantial development.

Research and development activities do not stop at the end of satellite commissioning of novel sensors, as it can take several years for their full capacity to be realized. Continuing to stimulate research and development interests and funding sources to encourage user engagement is important, as is identifying supporting agencies with the capacity to champion research to operations.

4.4 **Data-handling development and testing**

This activity includes the design and procurement of new satellite reception systems, as well as the upgrades to terrestrial network access (Internet, Regional Meteorological Data Communication Network (RMDCN), and National Research and Education Network (NREN) services) needed to handle the increased data rates. It also encompasses upgrades to observational databases, short- and long-term archives, internal networks, and general information technology capacity for visualization, monitoring and processing.

It is crucial that the procurement of data-handling systems start early to enable complete testing of all technical and scientific aspects of the processing chain.

4.5 **Data-processing development and testing**

The software used to process satellite observations may need to be adapted and potentially upgraded to accommodate data from a new satellite. The changes required may include:

- (a) Updating the local processing chain used to incorporate direct-broadcast (DB) data into level 0 (L0) and level 1 (L1) products;
- (b) Acquiring additional software to derive level 2 (L2) products;
- (c) Converting data into intermediate local formats and using data subsets for smaller regions of interest for observation databases and archiving;
- (d) Incorporating data monitoring and assimilation into NWP models;
- (e) Adapting the processing chain to locally generate higher-level products for specific applications using on-premises systems and/or the Cloud;
- (f) Integrating data into the operational user environment, including, for instance, into integrated visualization applications (with satellite, radar, surface and altitude observations and model outputs) for forecasters.

For example, adapting NWP assimilation to new satellite systems requires long lead times and has specific requirements regarding the availability of instrument and product data.

It is essential that synthetic test data, with realistic data volumes and appropriate operational formats, be used when conducting end-to-end tests of the data processing systems. These tests should be in the form of “stress-tests” in order to check that the systems are able to deal with the expected data volumes.

The changes required to ensure that the software can process the data from the new satellites will vary widely according to the needs and capabilities of each user organization and will require careful coordination with the users.

4.6 **Contributions to calibration and validation**

It has become a standard practice for NWP centres to participate in instrument calibration and validation activities for both LEO and GEO satellites. In addition, satellite operators monitor “first-guess-minus-observation” departures for L1 products as part of their calibration and validation activities, and feedback and impact analysis from NWP users have become integrated components in the calibration and validation process. These activities should also continue to ensure user readiness for new-generation satellites.

5. **CAPACITY DEVELOPMENT**

Capacity development is vital to ensure that all WMO Members are able to exploit the value of the new generation of satellite data to the maximum. Capacity-development activities can take the form of bilateral NMHS partnerships, regional collaborative mechanisms such as user forums or conferences, and WMO regional coordination groups on satellite data requirements. Training is one of the major elements of capacity development; it is focused on providing skills for using satellite data and products and should be considered of prime importance for both satellite operators and users.

Different aspects of user readiness for various target groups for training exist, and it is important to identify the categories needed as these will have different timescales and require different levels of information about the new satellite system.

The first type of training focuses on making sure the data can be accessed/received and displayed and is directed towards technical staff, including engineers and information technology specialists. This training addresses the questions: How and where can data and products be accessed? What types of commercial software or freeware programs/software codes are available to read data formats and where are they located?

The second type of training focuses on the research to operations to research loop. It includes testbed and proving ground activities. The overall goal is to evaluate the usefulness of the data or the products in a simulated operational setting and to make sure the data/products can be handled when they become available. This training typically consists of workshops or direct research/office interactions and is conducted with proxy data before satellite launches or with real data after the launches.

The third type of training focuses on the application of the new imagery and products in the operational setting. The generic satellite skills and knowledge necessary for operational forecasters should align with the WMO [Guidelines on Satellite Skills and Knowledge for Operational Meteorologists](#) (SP-12) to inform training development, implementation, and impact assessments, particularly as they relate to imagery interpretation. This type of training takes many forms: workshops, webinars, online modules, short reference videos and guides, and so forth. It should take place as close to the release of the new imagery and products as possible, and the best time to enhance information retention is after the launch of the satellite, when the user begins to explore the new imagery and products. Following up one-time formal training with regular and repeated informal training on imagery and products used for different weather phenomena and significant events will increase the adoption of new satellite products by user organizations.

A non-exhaustive list of identified training subjects includes:

- (a) Similarities and differences with respect to existing satellites;
- (b) Equipment operation and maintenance;
- (c) Interpretation of L1 data from satellite payload instruments including:
 - (i) Imagery interpretation;
 - (ii) Passive sounder data usage;
 - (iii) Active instrument usage;
- (d) The use of software tools (for processing, visualization, analysis and assimilation);
- (e) Derived L2 product utilization and interpretation;
- (f) Understanding data formats and dissemination;
- (g) The physical basis of remote sensing, in particular as it applies to new instruments.

Target groups for training include:

- (a) Trainers (using the “Train-the-Trainers” approach);
- (b) Managers of user-readiness projects;
- (c) Operational forecasters;
- (d) User communities in NWP and other application areas;
- (e) Organizational managers;
- (f) Technical support personnel;
- (g) Research and development personnel, and science-to-operations personnel.

The approach to organizing training depends very much on the needs and capabilities of the user organizations and on the organizational relationship between the satellite operators and the users. In 2020, the WMO Education and Training Office published *Global Campus Innovations* (WMO-No. ETR-27), which includes submissions from WMO Members on new learning approaches, curriculum advances, collaborations in education and training, and technology-enhanced learning. With these advances, the emphasis is shifting towards blended learning approaches that combine in-person courses and workshops, online self-study modules, webinars, peer-to-peer and mentor interactions, and informal regular regional focus group sessions that promote communities of practice and continued learning.

The increasing importance of continuing training activities after satellite launch needs to be emphasized. Training needs to cover both normal and critical real-weather situations for all seasons, and it must be based on the real characteristics of the satellite systems. Emphasis should also be given to management support of the blended learning approaches and Training for Trainers to enhance the development and delivery of training materials.

The new-generation GEO satellites launched in 2015–2025 have strong similarities in instrumentation (for example, similar spectral, temporal and spatial resolution of imagers and lightning mappers). Therefore, there are substantial potential benefits to users and satellite operators in developing common training material and in fostering common application development.

The WMO-CGMS Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) strategy covering the period 2024–2027 places high emphasis on building capacity among WMO Members for understanding and exploiting data from new-generation satellites. VLab is expected to play a key role over the coming years in addressing the training needs of meteorologists in this regard, and strong support from CGMS members will be required.

Capacity development should engage not only operational forecasters and satellite operators, but also the academic community. It is important to ensure that researchers and students participate in scientific activities related to the new instruments, in particular since this will benefit the operational exploitation of the instruments in the longer term by engaging the next generation of developers and users. In order to exploit the innovation potential of next-generation data, early engagement with the research community and their funding agencies is encouraged. Bringing together operational forecasters, product developers, the academic community and forecast users will contribute significantly to the rapid transition from research to operations and vice versa.

Training and user support is required beyond the user preparation phase. The user preparation phase is one period of activity within a broader and sustainable user engagement and capacity-development process.

6. SATELLITE SYSTEM DEVELOPMENT

The activities involved in executing a satellite system development programme are usually divided into the following seven phases (see the figure) and are typically performed by satellite operators in cooperation with research and development satellite agencies and industry partners.

- (a) Phase 0 – Mission analysis and needs identification;
- (b) Phase A – Feasibility;
- (c) Phase B – Preliminary definition;
- (d) Phase C – Detailed definition;
- (e) Phase D – Qualification and production;

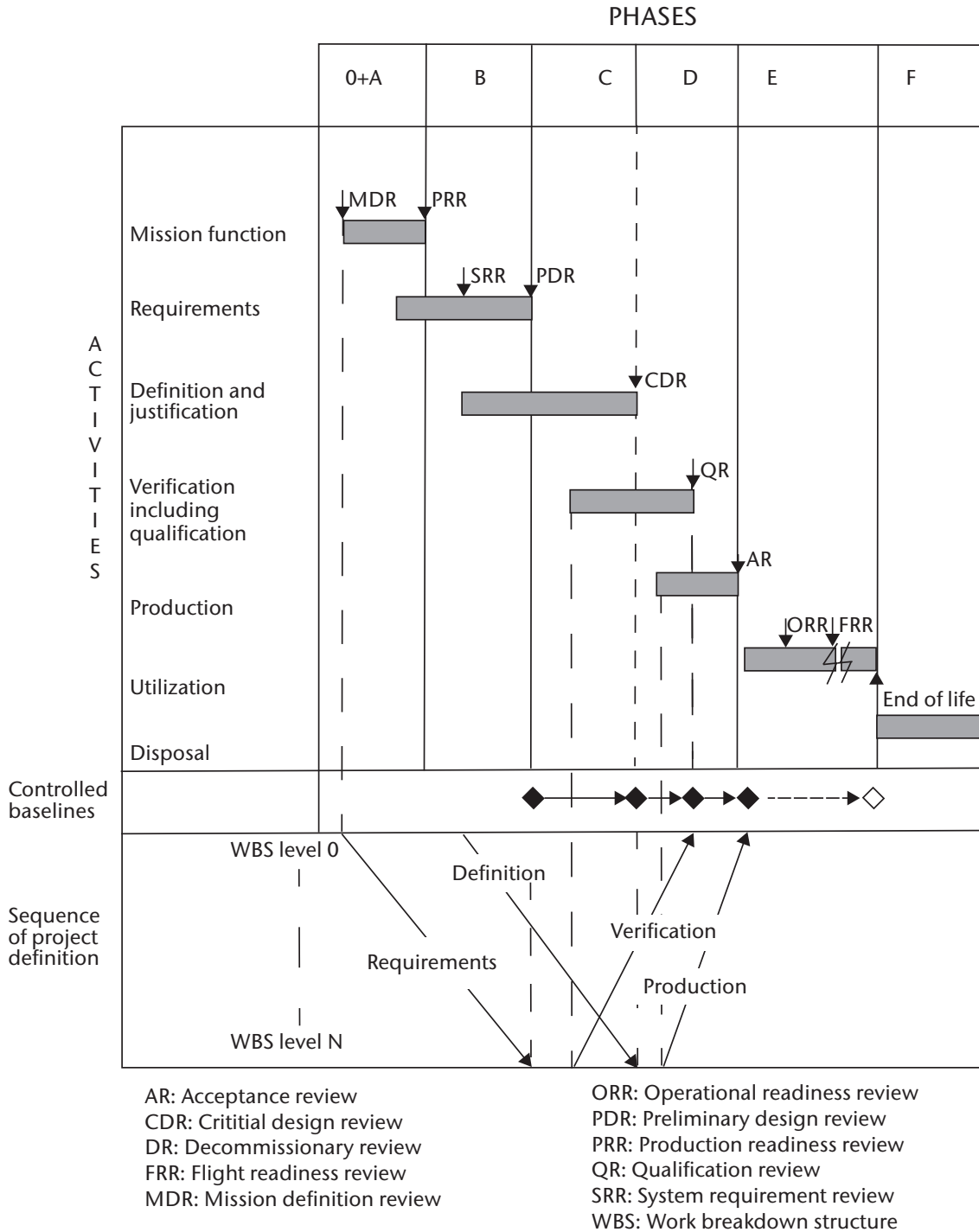


Figure. Reference satellite system development life cycle according to the European Cooperation for Space Standardization

(f) Phase E – Utilization;

(g) Phase F – Disposal.

Phase C (detailed definition) concludes with the system critical design review (CDR), at which point the definition of the system (satellite and ground segment) is complete down to the lowest level, and after which, full production (Phase D – qualification and production) of the system will start. If the development follows a nominal schedule, the system CDR will take place three years before the launch of the satellite. Phase E (utilization) starts with the shipment of the satellite

to the launch site and the start of launch preparations and is subdivided into Phase E1 (launch and commissioning), typically lasting until 6–12 months after launch, and Phase E2 (routine operations).

The most significant consequence of this life cycle, with respect to the user community, is that the system specifications and other information made available to the user community before the system CDR (at the end of phase C) will be based on the requirements, whereas the deliverables based on the real characteristics of the system will only become available after this time, during Phases D and E1.

This life cycle reflects actual experience relating to Meteosat Second Generation (MSG), Communication, Oceanography and Meteorology Satellite (COMS) and GOES-R and the planning for MTG. Variations exist for specific programmes; for example, the planning for Himawari-8 development was compressed: the system CDR was completed in January 2012, while the satellite was successfully launched on 7 October 2014.

7. **DELIVERABLES FROM SATELLITE DEVELOPMENT PROGRAMMES TO USER-READINESS PROJECTS**

This part of the *Guidelines* considers high-level specifications for the different items produced by the satellite development programmes that should be delivered to user-readiness projects. The timeline of the deliverables can be found in the [table](#).

7.1 **Instrument pre-launch calibration and characterization**

Pre-launch calibration and characterization data for satellite remote sensing instruments, being of general interest to the remote sensing data user community, are critical for the production of calibrated and geolocated L1 data and their adaptation by NWP and climate applications. The uncertainty, reproducibility and stability of these data are driven by operational and research remote sensing applications and requirements. For instruments built and/or tested by industrial partners, the provision of pre-launch test data to systems engineers, satellite operators and the remote sensing community are often subject to contractual constraints.

Satellite instrument pre-launch testing should strive to reproduce as closely as possible instrument operation in the predicted in-orbit environment. This is also known as “testing as you fly”. The calibration and characterization data produced by this testing ensure that the instrument to be flown is fully understood at launch and will meet its performance requirements when in orbit. The need for pre-launch instrument characterization is all the more important given the increasingly complex design of the new generation of instruments.

Estimates of several key performance parameters (listed below), including SRF characteristics, radiometric accuracies derived from pre-launch tests, and the radiometric characterization of onboard black bodies, will benefit from considering the property of metrological traceability. This requires all measured quantities influencing the estimate of a parameter to be linked, through an unbroken chain of comparisons, to recognized measurement standards, ideally the International System of Units (SI). Establishing such traceability enables the robust determination and optimization of uncertainties in these key performance parameters.

To facilitate their proper and efficient use by the international remote sensing community, pre-launch characterization data should include the following:

- (a) The appropriate channel naming and numbering convention and channel science application(s);
- (b) SRF (also known as relative or absolute radiometric spectral responsivity (RSR)):

- (i) Channel central frequencies/wavelengths and bandwidths, together with detailed measured spectral responses from pre-launch instrument characterization;
 - (ii) Responsivity versus wavelength as a function of the channel (that is, average) and detector;
- (c) Polarization for each channel, verified by pre-launch measurements;
 - (d) Along-scan and in-track FOV pixel size or full point spread function (PSF)/modulation transfer function (MTF);
 - (e) Instantaneous field of regard (IFOR)/instantaneous field of view (IFOV)/swath coverage, repeat cycle/orbit configuration;
 - (f) Measured antenna pattern (for MW instruments);
 - (g) Pixel sampling distance/time intervals;
 - (h) System-level instrument noise (that is, noise expressed as a variation in radiance and brightness temperature (NE_{dL} and NE_{dT}, respectively)) as a function of instrument and focal plane temperature and spacecraft voltage;
 - (i) Radiometric calibration and characterization:
 - (i) Gain and offset as a function of instrument and focal plane temperature;
 - (ii) Polarization sensitivity;
 - (iii) Radiometric resolution, dynamic range, linearity and quantization;
 - (iv) Response versus scan angle for scanning radiometers;
 - (j) Instrument pointing, geometric accuracy and band to band calibration/registration (that is, geometric performance);
 - (k) Expected mission and instrument lifetimes;
 - (l) Key parameters of on-board calibrators (that is, black-body emissivity and temperature uniformity, solar diffuser spectral bidirectional reflectance or transmittance distribution function (BRDF or BTDF) and uniformity);
 - (m) Target and realized measurement uncertainties for the above data;
 - (n) In all the above, the level of maturity of the determination of instrument testing parameters should be indicated. This is accomplished by identifying whether the data were determined using analysis/modelling, demonstration or inspection, or testing at the part, sub-assembly, subsystem, system or observatory (that is, spacecraft plus instruments) level.

Pre-launch test data should be provided for the primary, redundant and all potential cross-strap instrument in-orbit operational configurations.

Mechanisms must be established to provide users with information about events that affect in-flight instrument performance. To address this, the [Global Space-based Inter-calibration System \(GSICS\)](#) project coordinates the implementation of operational instrument event logs.

7.2 Product specifications

Product specifications include scientific specifications of the product algorithms, detailed specifications of formats for dissemination, as well as on-demand requests, information on timeliness and expected data volumes, all for both L1 and L2 products.

Community standard formats should be adopted for products, if not WMO's BUFR and GRIB, then netCDF with CF convention. For the latter, WMO is in the process of introducing netCDF CF profiles, and the concept of WMO-approved formats is evolving in this respect. It is also important to consider the flexibility which will come with the advent of the WMO Information System (WIS) 2.0. There is a need for a more standardized approach to describe both L1 and L2 products, potentially through the development of standard templates for product description. It is highly recommended that nicknames be avoided to describe the products. Nicknames lead to confusion among users (for example, it was reported by trainers that tropical users initially ignored using the "snow/ice" band at 1.6 μm because they did not experience snow and ice on the ground – they later realized it was useful for detecting the ice phase in clouds).

7.3 **Product guides**

In addition to formal product specifications (for example, algorithm theoretical basis documents (ATBDs)), several operators have successfully implemented product handbooks/user guides which help users assess the fitness for purpose of the products. A good example of these is the MTG product user guides generated by EUMETSAT. The content of these guides includes information that is helpful with respect to receiving, processing, and reading level 0–2 data (for example) and using those data as inputs for algorithms, products, and display systems.

7.4 **Data access mechanism specifications**

With the increasing use of cloud technology, the methods for accessing satellite products are developing rapidly. There is, however, a need for a range of access methods so that users who do not have reliable access to the Cloud can retrieve products reliably.

The methods for accessing satellite products directly typically include DB from the satellite itself and/or digital video broadcast (DVB)-based dissemination from telecommunications satellites. The corresponding specifications are required for the procurement of user reception systems.

The system requirements for DB reception systems, including both antennas, front-end components and computer systems for acquisition and L1 processing, need to be available to users in time for them to start their procurement activities, typically three years before launch. Processing system requirements are becoming increasingly demanding, with the complex processing of DB data for the new generation of satellites, and the impact on users' systems is significant. If the satellite operator can offer a remotely accessible (possibly cloud-based) processing solution for the DB data, the DB reception system will not necessarily need L1 processing capabilities. This approach is already being assessed by the China Meteorological Administration (CMA).

Also required are specifications of other near-real-time dissemination mechanisms employing terrestrial communication and cloud technology, as well as specifications for offline data access mechanisms, including archive retrieval and other on-demand means. For example, for data disseminated via the Global Telecommunication System (GTS), abbreviated bulletin headers are needed to organize the routing, and for data disseminated via the WIS 2.0 publication/subscription (pub/sub) infrastructure, the relevant topic(s) are needed to configure the consumers' subscriptions.

Where user registration is needed for access to products and services, a detailed description of the user registration process is required before launch so that users can carry out the registration process during the commissioning phase.

7.5 Software tools, documentation, and test data

Level 1 preprocessing software is required for the development of user data-processing functions, but in many cases, it is only available from an operator after ground segment acceptance. Any contracts for the procurement of data-processing systems need to take this into account to allow for early deliveries.

Software documentation, such as format books, user menus, ATBDs, need to be made available to users along with the software and test data.

Software tools can also be developed by experts in the user community, but for a new generation of satellites, these software tools will always depend on L1 processing kernels developed as part of the satellite system development.

Different categories of test data exist, with different life cycles. A universal categorization is not in use, but for the purposes of these *Guidelines*, the following terminology is used:

- (a) Synthetic data: No scientific value, but realistic sizes and formats; used for user data-flow testing;
- (b) Simulated data: Data simulated by forward radiative transfer model calculations. Simulated data are used to test processing and visualization tools. These data are produced based on NWP-model outputs; they generally do not contain realistic spatial structure and temporal variability;
- (c) Proxy data: Actual data sets from relevant precursor instruments – for example, 2.5-minute data from Meteosat-10 for MTG-Flexible Combined Imager (MTG-FCI), 1-minute super-rapid scanning data from GOES for GOES-R Advanced Baseline Imager (ABI), and Infrared Atmospheric Sounding Interferometer (IASI)/Atmospheric Infrared Sounder (AIRS) data for FY-4A Geostationary Interferometric Infrared Sounder (GIIRS) and MTG-Infrared Sounder (MTG-IRS). Proxy data are used in early training on capabilities and application areas. It is also possible to use proxy data to construct test data similar to simulated data by adding data simulated by radiative transfer models for channels to the data present in precursor missions or by using interpolation in time and space;
- (d) Pre-operational data: Real satellite data generated as part of the commissioning activities, but before full validation has been completed.

The operators should provide all of these categories of test data, use consistent terminology to describe them, and provide software tools for the use of the test data, both during pre-launch development and testing (where the focus should be on data for format familiarization and data-flow testing) and during post-launch commissioning activities (where pre-operational data are to be provided). Advanced users can also provide test data, and these data can be integrated with the test data supplied by the operators.

7.6 Operations plans and schedules

To ensure user readiness, it is important that both long-term plans, as well as routine schedules, be made available before the start of operations. These include the following elements:

- (a) Fly-out plan for the overall satellite programme, including launch plans, orbital positions and end-of-life dates, and information about overlap with existing operational satellites;
- (b) Routine operations schedule, including areas of coverage for flexible scanning operational scenarios and information on the process for scenario switching, for example, activation of super-rapid scanning operations for severe storms and tropical cyclone tracking;
- (c) If appropriate, conditions for user input with respect to the operations schedule (for example, requests for special mode-targeted operations);

- (d) Planning for routine spacecraft maintenance activities, such as orbital manoeuvres, seasonal spacecraft reorientation (yaw-flip), instrument decontamination, and the like;
- (e) Schedules for activation of LEO DB where applicable;
- (f) Schedules for routine dissemination for both DB and re-broadcast via telecommunications satellites.

Dialogue with key users is crucial when establishing the initial operations plans.

Details on recommended due-by dates are provided in the timeline contained in the [table](#).

7.7 Data access during early mission phases

A critical element for ensuring user readiness is the early provision of satellite products and the overlap with the previous system. Satellite products must be provided at the earliest opportunity following the necessary calibration-validation activities, and the data provision must, in all phases, as far as possible, use the operational data access infrastructure. A sufficient overlap with the existing operational satellite system must be provided to support the operational introduction of the new satellite data. The critical needs are:

- (a) Periods of pre-launch dissemination of test data to support the testing of users' data acquisition infrastructure;
- (b) Access to non-validated data by selected users supporting calibration-validation activities;
- (c) Early post-launch dissemination of pre-validated data and products;
- (d) Parallel L1 data dissemination, from both old and new satellites (as long as possible, but for a minimum of six months after the end of commissioning (typically until L+1y))

More details are included in the reference user-readiness project timeline.

7.8 User notification and feedback

It is essential that the satellite operator establish two-way communication channels with the user community to provide general and specific information and to allow users to make enquiries and provide other feedback during the preparation phase. Such channels are also necessary to provide routine user support starting from the commissioning phase and continuing throughout the routine operations phase. Identifying and mapping the networks that reach different user communities allows for strategic and efficient communication.

Such communication should include, but is not limited to, the WMO regional coordination groups on satellite data requirements, regional forums and user conferences, and training events. The communication channels should also provide support for enquiries and feedback from individual users.

7.9 Training resources

For new satellite systems, the provision of training material from satellite operators is crucial. Blended training approaches are of increasing importance and provide flexibility when delivering new information about the satellite and its applications as it becomes available. It is also essential to capitalize on the contributions of the user community and promote training resources that are made available by user groups. WMO-CGMS VLab plays a key role in developing and delivering online training material to users worldwide in their native languages. Regional forums and user conferences held annually or every other year by satellite operators provide the best opportunity to deliver information on new-generation satellites and gather

user input to inform the requirements of the next generation of satellites. Training workshops are coordinated with the conferences and can be targeted to specific user groups. Blending and interleaving workshops, courses, webinars, online modules, blogs, and regular regional focus group sessions promotes continued learning and the uptake of satellite imagery and products. VLab is actively engaged in these activities.

7.10 **Other deliverables**

For many applications, it is important to have the set of fundamental constants that have been used to derive satellite data and products; satellite operators should make these constants available to users. The proposal of a common standard to be used by CGMS operators is planned.

8. **TIMELINE FOR THE REFERENCE USER-READINESS PROJECT**

The [table](#) shows the overall timeline of user preparedness activities and the planning for the different deliverables needed to support these activities starting from the initial stages of satellite system development.

Table. Timeline for the reference user-readiness project

<i>Time relative to launch date (L) in years (y) or months (m)</i>	<i>Satellite system development: Activities and milestones</i>	<i>User-readiness project: Activities and milestones</i>	<i>Needed deliverables from satellite operators</i>
L-5y -> L-4y	Ground segment development Phase C	<ul style="list-style-type: none"> - Initiation of user (for example, NMHS)-readiness project - Initiation of cooperative projects addressing needs of less developed WMO Members 	<ul style="list-style-type: none"> - Identified likely and potential users - Overall specifications of user segment, including high-level definition of migration path from existing user segment - Preliminary schedule for deliverables to users - Identified research and development needs (observation operators/radiative transfer, and so forth)
L-4y -> L-3y	System CDR	<ul style="list-style-type: none"> - Identification of drivers for investment and running costs - Planning and allocation of human resources and budgets for investments and running costs - Establishment of prioritized data requirements, as clear priorities for current and future products allow the best preparations to be made for establishing data access and delivery capabilities - Initial training on capabilities for trainers and decision-makers 	<ul style="list-style-type: none"> - General description of instruments - General description of near-real-time dissemination mechanisms - Detailed specifications of L2 and L1 products to be available at start of operations (Day-1 products) - Proxy test data - Plans for evolution of products after start of operations (Day-2 products)

<i>Time relative to launch date (L) in years (y) or months (m)</i>	<i>Satellite system development: Activities and milestones</i>	<i>User-readiness project: Activities and milestones</i>	<i>Needed deliverables from satellite operators</i>
L-3y -> L-2y	<ul style="list-style-type: none"> - System production - On-ground characterization of instruments 	<ul style="list-style-type: none"> - Design of new reception system - Design of communications network changes, including GTS/Regional Meteorological Data Communication Network (GTS/RMDCN) capacity - Design of new data-handling and processing functions - Training on specific application areas, based on proxy data, for trainers and senior forecasters 	<ul style="list-style-type: none"> - Specifications of instruments and their performance, including planned SRFs, noise and FOV size - Simulated test data - Developed applications where required (for example, observation operators, methodologies, and so forth) - Detailed specifications of near-real-time dissemination mechanisms - Detailed specifications of DB, including frequency and signal characteristics, and hardware specifications for antennas, front-end components and computer systems for the acquisition and processing of DB data - General description of offline data access - Data/product volume estimates - Data/product format definitions - Fundamental constants used in processing - Data access conditions (for example, licensing, key units) - L1 preprocessing software for DB (preliminary version) - Establishment and use of two-way communication channels for user enquiries
L-2y -> L-1y	Ground system acceptance	<ul style="list-style-type: none"> - Procurement, installation and acceptance testing of systems - Software design for data processing, including NWP ingest - Training on specific application areas, based on proxy data, for trainers and senior forecasters 	<ul style="list-style-type: none"> - Full pre-launch instrument characterization information (including SRFs, noise) - Information on radiative transfer models (for example, RTTOV) that support instruments - Synthetic test data (including L1B data format details, satellite identifier, navigation information) - Continuous periods of test dissemination of synthetic data - Long-term operations plan - Planning for data exchange to serve the global community
L-1y -> L-6m	Flight readiness of satellite	End-user training (forecasters)	<ul style="list-style-type: none"> - Start of regular updating of plans for launch and commissioning

<i>Time relative to launch date (L) in years (y) or months (m)</i>	<i>Satellite system development: Activities and milestones</i>	<i>User-readiness project: Activities and milestones</i>	<i>Needed deliverables from satellite operators</i>
L-6m -> L	Operational system validation and launch preparations	<ul style="list-style-type: none"> - Data-processing software testing (using proxy data) - Technical training on reception systems and other system elements - Data acquisition system testing (using synthetic data) 	<ul style="list-style-type: none"> - Simulated test data based on pre-launch instrument characterization - L2 data format - DB software package (if DB available) - User documentation for dissemination mechanisms and delivered software tools - Routine operations schedule
L -> L+6m	<ul style="list-style-type: none"> - Satellite in-orbit verification - Commissioning of L1 products 	<ul style="list-style-type: none"> - Full system and software testing (using pre-operational data) - Support to operators' calibration/validation activities, in particular through NWP assimilation 	<ul style="list-style-type: none"> - Early dissemination of unvalidated L1 data - Early switch-on of DB - Pre-operational L1 data dissemination - In-flight characterization of instrument performance - L1 preprocessing software for DB (operational version) - Start of routine user support
L+6m -> L+2y	Commissioning of L2 products	<ul style="list-style-type: none"> - Scientific data exploitation (iterative, based on an increased understanding of real data) - Post-launch training based on real data - Declaration of user operational readiness 	<ul style="list-style-type: none"> - Operational L1 data dissemination from both old and new satellites (as long as possible, but at least until L+1y)

For more information, please contact:

World Meteorological Organization

7 bis, avenue de la Paix – P.O. Box 2300 – CH 1211 Geneva 2 – Switzerland

Strategic Communications Office

Tel.: +41 (0) 22 730 83 14

Email: cpa@wmo.int

wmo.int