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Assessment of Solution-Agnostic Observational Needs for Global Numerical Weather Prediction (NWP)

Corresponding authors:

Sid Boukabara (NOAA/NESDIS/OSAAP)
Frank Gallagher (NOAA/NESDIS/OSAAP)
David Helms (NOAA/NESDIS/OSAAP/TPIO)
Satya Kalluri (NOAA/NESDIS/JPSS)

Contributing authors (Core-SAT Members):

J. Gerth, S. Swadley, M. Goldberg, D. Kleist, F. Iturbide-Sanchez and J. Yoe

Members of the SAT subcommittee on GNWP:

R. Anthes, R. Atlas, K. Garrett, R. Hoffman, W. McCarty, B. Ruston, J. Yoe, S. Bunin

US DEPARTMENT OF COMMERCE
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NESDIS Office of System Architecture and Advanced Planning (OSAAP)
1335 East West Highway, SSMC1, Silver Spring, MD 20910

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Table of Contents

Executive Summary

The NESDIS next-generation space architecture planning and development process requires a thorough understanding of the observational needs (current and expected in the future) by the major users and their applications in order to better design data acquisition projects and programs of the future. These user needs have to be captured at a high level of granularity to provide useful information for the design of the next generation architecture (in terms of design of sensors, antennas, and constellations' orbits, swaths, etc). For example, knowing the relative importance of the spatial resolution and precision of a variable needed by the users will help in defining the relative importance of designing a sensor with the optimum combination of antenna size, number of channels, and associated noise levels. One of the major applications using satellite data is global Numerical Weather Prediction (GNWP), which is the focus of this report. Forthcoming reports will address observational needs of applications such as nowcasting, atmospheric composition monitoring and forecasting, ocean forecasting, etc. Sources of observational needs are varied. They have for example been captured through User Engagement activities and through previous requirements collection exercises. The NESDIS Systems performance Assessment Team (SAT) has recently undertaken the effort of reviewing many of these sources then commissioned an effort to update these needs (led by a SAT subcommittee of subject matter experts on GNWP), and to work toward consolidating these observational needs for GNWP into this single, referenceable technical report. Some of the high-level findings and main recommendation are listed below.

- ***Fact:*** The GNWP system is a major application using satellite data. It is foundational because of its wide reliance across the users' community because many applications incorporate the output of GNWP as guidance, boundary conditions, and other inputs.
- ***Fact:*** In order to design the highest value cost-effective constellation of space satellites and sensors, it is important to capture the observational needs in a solution-agnostic fashion, balancing the ranges of the required observations and their relative priorities.
- ***Fact:*** Multiple efforts have taken place in NESDIS to capture observational needs. These efforts should be consolidated as much as possible, including OSAAP/TPIO activities, and Programs-led activities.
- ***Findings:*** The tables presented in this report summarize the global NWP observational needs, as found through multiple deliberations with NWP experts, several prior established expert groups, and Line Offices, and consolidated and adjudicated through the Government-only Core-SAT.
- ***Recommendation:*** We recommend that NOAA use these solution-agnostic GNWP observational needs (outlined in the tables below) as an input to the establishment of the NOAA observational requirements for current NWP. These include variables, attributes' ranges of these variables, as well as associated prioritizations. These should also be considered as part of the planning and development of next-generation space architecture and products development (PLR generation).

Background

NESDIS has to regularly assess the user mission ***needs*** for environmental observations. This is important in order to (1) remain in tune with the evolution of these needs and to (2) better plan for the next-generation architecture, and in particular, the space-based architecture. To achieve this goal, these needs have to be collected from a broad community, in a solution-agnostic fashion, in order to provide a reference for multiple observing systems solutions that will be able (1) to meet these needs now and in the future, (2) to look at innovative ways to meet all needs cost-effectively, and (3) to potentially fill existing gaps or reduce them. It is important to note that these needs are expressed from a relatively wide community of observations' users, but it is important to highlight they do not constitute ***requirements*** for NOAA. An internal NOAA process exists to define observational requirements.

In order to perform the assessment of observational needs, a series of Systems performance Assessment Team (SAT) meetings took place over the summer and fall of 2021. The SAT is a NOAA technical team that has a diverse set of expertise in remote sensing, data assimilation, impact assessment, sensors engineering, calibration, meteorology, oceanography, land/hydrology, etc. The meetings purposefully included representatives from academia, private sector and NASA, all members of the SAT, and in NOAA, from line offices, and the OSAAP Analysis Team (TPIO) in charge of stewarding and updating the Consolidated Observational User Requirements List (COURL), as well as representatives from the major programs, who ultimately will be charged with developing the components of the space architecture (both LEO and GEO). The first of these meetings aimed at identifying the major applications that depend on the observations NESDIS provides. This was led by the NESDIS Chief Scientist. One of these applications that was identified is Global NWP (GNWP). A SAT subgroup, made up of subject matter experts in GNWP, led by Dr. Rick Anthes was established (with representatives from NOAA, NASA, DoD, and academia) to determine these observational needs. The overall goals of the group included determining which variables and what attributes of those variables are expected to be most important for global NWP in the 2030 timeframe. For example, NOAA needs to understand what are the realistic performance ranges of these needs and what are their associated NOAA priorities. The group also reviewed many previous impact and requirements studies to aid their development of the needs list.

It is the purpose of this report, drafted and reviewed by the Government-only Core-SAT team, to document and establish factual information about the needs of GNWP by assessing the users' needs for global NWP from many sources.

Note: It is important to note that the information captured is in geophysical space which is consistent with the international standard established by the WMO (e.g., the OSCAR database). This means that what is captured here is the information content needed for the observations. It does not mean that the GNWP systems will assimilate those products. Operational GNWP systems assimilate both radiances and derived geophysical products. Radiances in this case are tuned to maximize the information content of a particular geophysical variable. This is what is captured in this exercise, in a solution-agnostic fashion.

Sources of GNWP Observational Needs

The Core-SAT team, composed of federal employees from NOAA (including representatives from the NOAA OSAAP Analysis Team, and the NOAA LEO and GEO Programs), NASA (including the NOAA-NASA NWP group), and the DoD reviewed the GNWP observational needs by assessing the users' needs as developed by this SAT subgroup mentioned previously, but also with the findings from the following sources:

- GNWP needs identified by the Space Platform Requirements Working Group (SPRWG)
- GNWP needs identified by the GeoXO Requirements Working Group (XORWG)
- User engagement events by the LEO program through MW and IR workshops
- Impact assessment activities (OSEs) performed by NOAA and non-NOAA teams (especially the WMO international workshop on Observing Systems Impact on NWP)
- GNWP needs identified by the NOAA-NASA future NWP group
- Incorporating work done by OSAAP Analysis Team
- National Academy of Sciences Decadal Survey

All these needs were incorporated into a single document, using a prioritized, vetted list of variables with an agreed upon format (e.g., choice of units, etc.). This will allow for a better understanding of the overall GNWP needs, a streamlining of the process to collect observational needs, and minimizing the outreach to users. The requirements ranges, and their associated priorities, will also serve as an input to the Advanced Systems Performance Evaluation tool for NOAA (ASPEN). ASPEN is a dynamic and user-friendly tool that rapidly assesses the value of environmental data obtained from observing systems. It provides numerical scores of the benefits of existing and proposed sensors and constellations to a single or group of user applications. ASPEN addresses the technical and scientific performance factors and also provides a benefit/cost ratio value assessment. It is designed to be a science-based approach to perform comparative assessment of observation systems to support the decision process to assess potential future architecture solutions and their abilities to meet users' needs.

Observational Needs and Associated Priorities for Global NWP

The following tables represent the main findings, as summarized by the Core-SAT team, based on all the inputs mentioned above, including the sub-committee findings.

Table 1. Identifies geophysical variable priorities for the Global NWP application as reviewed by the Core-SAT using the values from the subcommittee on NWP as an input, as well as considering other sources (TPIO, NASA-NOAA working group on NWP, XORWG, etc.), and harmonized by OSAAP Team Analysis.

Table 2. Shows the variable performance ranges for the Global NWP application, as determined by the Core-SAT. These data are based on the SAT sub-committee on NWP's most recent findings as well as input from the OSAAP Analysis Team, and other considerations/sources, as mentioned above. Data ranges, shown as triplets, are defined as "minimally useful," "expected [in the 2030 time frame]," and "maximum effective" values. Current geophysical variable performance ranges are listed as well.

Table 3. Includes Global NWP application attribute priorities, per variable, including horizontal and vertical resolution, temporal resolution, error standard deviation, and data latency. This table was provided by the OSAAP Analysis Team based on differential attribute change per unit time in the vertical and horizontal dimensions and the expected degradation to model predictability as a consequence of not updating the variable in the model. Current attribute weights per geophysical variable are listed.

Conclusions

The observational needs for the global NWP application have been collected in the past by different groups in NESDIS, in various ways, using different definitions, different variables, different units, etc. This was partly because it was done through different mechanisms over the last few years, including through the SPRWG team, the XORWG team, and through OSAAP Analysis Team interactions with direct NOAA users, etc. This latest round of observational needs collection was designed to consolidate the set of needs, defined in a way that helps the design and evaluation of the next-generation space architecture, but also to serve as a reference for all those interested in these needs in the near future. This was done as part of the Systems performance Assessment Team (SAT), and, in particular, the government-only Core-SAT. As stated previously, the collection of user needs was developed and reviewed by a variety of different sources that included representatives from the OSAAP Analysis Team, OSAAP/TPIO, the LEO and GEO programs, and representatives from the NOAA LOs, NASA, DoD, and academia, but the final determination of the list of user needs and attributes was conducted by the Core-SAT. Because this report relates to the current NWP needs, it is expected that a similar exercise be undertaken to project these needs in the *future* to account for the evolution of the models. This exercise of collecting observational needs should be refreshed regularly, to maintain an up to date awareness of the observational needs.

List of Tables

Table 1. Geophysical Variable Priorities for global NWP: List of the geophysical information and their prioritization (based on a scale from 0: non-important to 1: critically important), needed by current Global NWP systems as determined by the Systems performance Assessment team (SAT). This list was consolidated using a multitude of sources and follows the variables definition and units used in the ASPEN tool.

Geophysical Variable	Symbol/Abbreviation	Units	Priority
Air Temperature: Profiles	T(z)	K	1.00
Cloud Liquid Water Path	LWC	g/m2	0.20
Cloud Top Temperature	CTT	K	0.20
Normalized Difference Vegetation Index	NDVI	unitless	0.15
Specific Humidity: Profiles	RH	%	0.70
Sea Ice Concentration	SIC	%	0.20
Sea Surface Temperature	SST	K	0.20
Snow Cover	SC	%	0.15
Snow Water Equivalent	SWE	cm	0.05
Soil Moisture: Surface Wetness	W	m3/m3	0.10
Surface Pressure	SfcP	hPa	0.80
Wind Speed Profile: Eastward	u	%	0.80
Wind Speed Profile: Northward	v	%	0.80

***Current Geophysical Variable Need**

Table 2. Global NWP Observational Need Attribute Range: List of observational needs of the current GNWP system in NOAA. These needs are expressed in terms of ranges between minimally useful, expected level and maximum usefulness level. These attributes include the spatial coverage, the horizontal resolution, the temporal refresh, the uncertainty (in standard deviation) and the latency and when appropriate the vertical resolution, for all the variables listed in table 1.

Geophysical Variable	Units (Accuracy)	Geographic Coverage (dimensionless)	Horizontal Resolution (km)	Temporal Refresh (h)	Vertical Resolution (m)	Error Standard Deviation	Data Latency (h)
Air Temperature: Profiles	K	Global	[100,10,5]	[12,3,1]	[1000,500,100][1]	[2,1,0.5]	[6,1,0.25]
Cloud Liquid Water Path	g/m2 (%)	Global	[100,10,5]	[12,3,1]	[1000,500,100][2]	[10,5,2]	[6,1,0.25]
Cloud Top Temperature	K	Global	[100,10,5]	[12,3,1]	NA	[10,5,1]	[6,1,0.25]
Normalized Difference Vegetation Index	unitless	Global	[100,10,5]	[240,120,24]	NA	[0.25,0.15,0.1]	[240,24,3]
Specific Humidity: Profiles	%	Global	[100,10,5]	[12,3,1]	[1000,500,100][2]	[15,10,5]	[6,1,0.25]
Sea Ice Concentration	%	Global	[100,10,5]	[120,24,3]	NA	[25,15,10]	[120,24,3]
Sea Surface Temperature	K	Global	[100,10,5]	[120,24,3]	NA	[4,2,1]	[120,24,3]
Snow Cover	%	Global	[100,10,5]	[120,24,3]	NA	[25,10,5]	[120,24,3]
Snow Water Equivalent	cm	Global	[100,10,5]	[120,24,3]	NA	[8,4,2]	[120,24,3]
Soil Moisture: Surface Wetness	m3/m3	Global	[100,10,5]	[120,24,12]	NA	[0.2,0.1,0.05]	[120,24,3]
Surface Pressure	hPa	Global	[100,10,5]	[12,3,1]	NA	[1,1,0.5]	[6,1,0.25]
Wind Speed Profile: Eastward	m/s (%)	Global	[100,10,5]	[12,3,1]	[1000,500,100][1]	[20,10,5]	[6,1,0.25]
Wind Speed Profile: Northward	m/s (%)	Global	[100,10,5]	[12,3,1]	[1000,500,100][1]	[20,10,5]	[6,1,0.25]

*** Current Geophysical Variable Need**

Notes:

1. Vertical Domain: Surface to 80km
2. Vertical Domain: Surface to tropopause (~10km at equator)

Table 3. Global NWP Observational Need Attribute Priority: List of the GNWP needed variables as prioritized in table 1. This table contains the relative importance of the attributes or each of the variables. This is important for allowing the engineers and designers of sensors and constellations, to assess where emphasis should be put when performing trade studies. The way to read this table: for each row (variable), the weights between 0 (no importance) and 1 (highest importance) is assigned to the individual attributes such as temporal refresh, horizontal resolution, uncertainty standard deviation), etc.

Geophysical Variable	Geographic Coverage	Horizontal Resolution	Temporal Refresh	Vertical Resolution	Error Standard Deviation	Data Latency
Air Temperature: Profiles	0.8	0.6	0.7	0.5	0.4	1.0
Cloud Liquid Water Path	0.8	0.7	0.7	0.7	0.6	1.0
Cloud Top Temperature	0.8	0.6	0.7	NA	0.4	1.0
Normalized Difference Vegetation Index	1.0	0.8	0.6	NA	0.5	0.7
Specific Humidity: Profiles	0.8	0.6	0.7	0.5	0.4	1.0
Sea Ice Concentration	1.0	0.8	0.6	NA	0.4	0.7
Sea Surface Temperature	1.0	0.8	0.6	NA	0.5	0.7
Snow Cover	1.0	0.8	0.6	NA	0.5	0.7
Snow Water Equivalent	1.0	0.8	0.6	NA	0.5	0.7
Soil Moisture: Surface Wetness	1.0	0.8	0.7	NA	0.6	0.7
Surface Pressure	1.0	0.8	0.8	NA	0.7	1.0
Wind Speed Profile: Eastward	0.8	0.7	0.8	0.7	0.6	1.0
Wind Speed Profile: Northward	0.8	0.7	0.8	0.7	0.6	1.0

*** Current Geophysical Variable Need**

Abbreviations and Acronyms

ASPEN	Advance Systems Performance Evaluation tool for NOAA and NESDIS
COURL	Consolidated Observational User Requirements List
DoD	Department of Defense
GEO	Geostationary earth
Geo-XO	Geostationary earth and extended orbits
GNWP	Global Numerical Weather Prediction
JPSS	Joint Polar Environmental Satellite
LEO	Low Earth Orbit
LO	NOAA Line Office
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OSAAP	Office of System Architecture and Advanced Planning
OSCAR	Observing Systems Capability Analysis and Review Tool
OSE	Observing System Experiment
PLR	Program Level Requirements
SAT	Systems performance Assessment Team
SPRWG	Space Platform Requirements Working Group
TPIO	Policies, Procedures, & Systems Assurance Division
WMO	World Meteorological Organization
XORWG	GeoXO Requirements Working Group

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