UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA AND INFORMATION SERVICE

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SUBJECT: Assessment of Solution-Agnostic Observational Needs for Nowcasting Applications of Winter Precipitation Forecasting

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 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 nowcasting applications for winter precipitation, which is the focus of this memo.

- ***Fact:*** Understanding precipitation type and quantity is critical for forecasting winter weather such as snow, sleet, and freezing rain and is especially important for ground and aviation transportation.
- ***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:*** While satellite data is important for nowcasting applications, it is not the only observing source used.
- ***Findings:*** The tables presented in this memo summarize the nowcasting for winter precipitation observational needs, as found through multiple deliberations with nowcasting 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 nowcasting winter precipitation observational needs (outlined in the tables below) as an input to the establishment of the NOAA observational requirements for nowcasting. 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 requirements, space architecture, and products development 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 reducing 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.

Nowcasting is forecasting for the following six hours. The Nowcasting subcommittee focused on six application areas where satellites would play a major role as an observational source. Surveys were sent to NWS forecasters and the results of those surveys were used to come up with the initial observation ranges. In order to perform the assessment of observational needs for nowcasting, a series of SAT meetings took place over the spring and summer of 2022. These purposefully included representatives from academia, private sector and NASA, all members of the SAT, and in NOAA, from line offices, and the SAE Analysis Team (TPIO) in charge of stewarding and updating the *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).

One of the nowcasting meetings aimed at identifying the observational needs for winter precipitation data. It is important to be able to accurately forecast winter precipitation type and amounts for safe ground transportation and air travel. An SAT subgroup was established to determine these observational needs. The team was led by Jordan Gerth and made up of subject matter experts in nowcasting for winter precipitation, with representatives from NOAA/NWS. The overall goals of the group included determining which variables and what attributes of those variables are expected to be most important for winter precipitation nowcasting 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 memo, drafted and reviewed by the Government-only Core-SAT team, to document and establish the needs of nowcasting applications by assessing the users' needs for winter precipitation products 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 user systems will assimilate those products. This exercise captured user needs in a solution-agnostic fashion.

Sources of Winter Precipitation Observational Needs:

The Core-SAT team, composed of federal employees from NOAA (including representatives from the NWS, NOAA SAE Analysis Team, and the NOAA LEO and GEO Programs) reviewed the winter precipitation nowcasting observational needs by assessing the users' needs as developed by this SAT subgroup mentioned previously, but also with the findings from the following sources:

- "Guidelines for Nowcasting Techniques." World Meteorological Organization, 2017 edition. https://library.wmo.int/doc_num.php?explnum_id=3795.
- Nowcasting needs identified by the Space Platform Requirements Working Group (SPRWG)
- Nowcasting needs identified by the GeoXO Requirements Working Group (XORWG)
- User engagement events by the LEO program
- Incorporating work done by SAE Analysis Team
- Community of Practice, product baseline, and user value chain coordination through the User Engagement Council

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 nowcasting 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 ASPEN tool, which is used to assess potential future architecture solutions and their abilities to meet users needs.

Observational Needs and Associated Priorities for Winter Precipitation Nowcasting:

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. Describes the list of variables needed for the winter precipitation forecasting application, why they are important for the application, and whether they are already identified as an existing variable in the TPIO databases.

Table 2. Identifies geophysical variable priorities for the winter precipitation nowcasting application as reviewed by the Core-SAT using the inputs from the nowcasting survey of NWS meteorologists as an input, as well as considering other sources (TPIO, NASA-NOAA, XORWG, etc.), and harmonized by SAE Team Analysis.

Table 3. Shows the variable performance ranges for the winter precipitation nowcasting application, as determined by the Core-SAT. These data are based on the input from the nowcasting survey of NWS meteorologists as well as input from the SAE 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 4. Includes winter precipitation nowcasting application attribute priorities, per variable, including horizontal and vertical resolution, temporal resolution, error standard deviation, and data latency. This table was provided by the SAE Analysis Team based on differential attribute change per unit time in the vertical and horizontal dimensions. Current attribute weights per geophysical variable are listed.

Conclusions:.

The observational needs for the winter precipitation forecasting 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 SAE 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 SAE Analysis Team, SAE/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. This exercise of collecting observational needs should be refreshed regularly, to maintain an up to date awareness of the observational needs.

CC:
Core-SAT Members relevant to this memo:

SAT sub-committee on Winter Precipitation Nowcasting: J. Gerth, M. Sporer, J. Zvolensky, J. Rabinowitz, C. Jones, J. Michael, D. Zaff,, S. Bunin

Table 1. Winter Precipitation Forecasting Variable Needs: List of the variables needed by the winter precipitation forecasting application, the importance of these variables, and a notation about the variable status in the TPIO databases. Precip Rate/Snowfall Rate is required in layers. For Precip Rate and Snowfall Rate, an alternative is to define this at the surface and rain (snow) water path in layers.

Geophysical Variable	Variable Importance	TPIO Database (Existing/ New)
Relative Humidity	The amount of moisture in the air can determine the possibility of precipitation	E
Wind Speed Profile	Can impact snow to liquid ratios and also need to be factored in for wind chill temperatures	E
Cloud and Moisture Imagery	High resolution datasets are used in visualization systems to monitor hazards	E
Air Temperature: Profiles	Air temperature throughout the atmosphere can determine the type of winter precipitation (i.e., rain, sleet, snow, freezing rain, etc)	E
Total Precipitable Water	A measure of the amount of moisture potentially available in the atmosphere for precipitation	E
Land Surface Temp	The temperature at the surface can help determine if snow will or ice will accumulate	E
Snow Cover	Can have an impact on snow-water ratios	E
Snow Depth	Can estimate the amount of snow-liquid for melting and can be a factor with blowing snow	E
Snow Grain Size	The size and composition of snow can help determine how quickly it will stick to the ground	N
Cloud Top Temperature	Gives be an indicator of cloud growth and likelihood of precipitation	E
Precip Rate/Snowfall Rate	Helps to determine the intensity of snowfall and forecast the depth of snow	E
Cloud Base Height	Can impact the surface temperature and the amount of radiational cooling, which may affect the winter precipitation type	E

Table 2. Geophysical Variable Priorities for Winter Precipitation Nowcasting: List of the geophysical information and their prioritization (based on a scale from 0: non-important to 1: critically important), needed for current winter precipitation nowcasting 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
Relative Humidity	RH	%	0.9
Wind Speed Profile	u, v	m/s	0.8
Cloud and Moisture Imagery	CMI	unitless	0.9
Air Temperature: Profiles	T(z)	K	1.0
Total Precipitable Water	TPW	mm	0.8
Land Surface Temp	LST	K	0.7
Snow Cover	SC	%	0.7
Snow Depth	SD	m	0.7
Snow Grain Size	SGS	mm	0.7
Cloud Top Temperature	CTT	K	0.7
Precip Rate/Snowfall Rate	SFR	mm/hr	1.0
Cloud Base Height	CBH	km	0.7

*** Current Geophysical Variable Need**

<u>Table 3. Winter Precipitation Observational Need Attribute Range:</u> List of observational needs of the current winter precipitation nowcasting systems 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)	Images	Geographic Coverage (dimensionless)	Horizontal Resolution (km)	Horizontal Density (100 km-2)	Temporal Refresh (h)	Vertical Resolution (km)	Error Standard Deviation	Data Latency (h)
Relative Humidity (%)	%	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[3 h, 15 m, 2 m]	[1, 0.5, 0.1]	[10, 5, 2]	[1 h, 5 m, 1 m]
Wind Speed Profile (m/s)	m/s	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[3 h, 15 m, 2 m]	[1, 0.5, 0.1]	[5, 2, 1]	[1 h, 5 m, 1 m]
Cloud and Moisture Imagery (unitless)	unitless	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[1 h, 5 m, 1 m]	NA	NA	[15 m, 1 m, 0.5 m]
Air Temperature: Profiles (K)	K	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[3 h, 15 m, 2 m]	[1, 0.5, 0.1]	[5, 2, 1]	[1 h, 5 m, 1 m]
Total Precipitable Water (mm)	mm	TRUE	CONUS+AK+HI+ US Territories	[10, 2, 0.5]	[1, 25, 400]	[3 h, 15 m, 2 m]	NA	[10, 5, 2]	[1 h, 5 m, 1 m]
Land Surface Temp (K)	K	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[6 h, 1 h, 15 m]	NA	[5, 2, 1]	[3 h, 15 m, 2 m]
Snow Cover (%)	%	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[6 h, 1 h, 15 m]	NA	[25, 10, 5]	[3 h, 15 m, 2 m]
Snow Depth (m)	m	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[6 h, 1 h, 15 m]	NA	[0.5, 0.25, 0.1]	[3 h, 15 m, 2 m]
Snow Grain Size (mm)	mm	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[6 h, 1 h, 15 m]	NA	[2, 1, 0.5]	[3 h, 15 m, 2 m]
Cloud Top Temperature (K)	K	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[6 h, 1 h, 15 m]	NA	[5, 2, 1]	[3 h, 15 m, 2 m]
Precip Rate/Snowfall Rate (mm/hr)	mm/hr	TRUE	CONUS+AK+HI+ US Territories	[2, 0.5, 0.25]	[25, 400, 1600]	[1 h, 5 m, 1 m]	[4, 2, 0.5]	[25, 10, 5]	[15 m, 1 m, 0.5 m]
Cloud Base Height (km)	km	TRUE	CONUS+AK+HI+ US Territories	[5, 1, 0.25]	[4, 100, 1600]	[1 h, 5 m, 1 m]	NA	[0.5, 0.25, 0.1]	[15 m, 1 m, 0.5 m]

Table 4. Winter Precipitation Nowcasting Observational Need Attribute Priority: List of the winter precipitation nowcasting variables needed 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	Images	Geographic Coverage	Horizontal Resolution	Horizontal Density	Temporal Refresh	Vertical Resolution	Error Standard Deviation	Data Latency
Relative Humidity (%)	0.5	0.8	0.9	0.9	0.9	0.9	0.5	1.0
Wind Speed Profile (m/s)	0.5	0.8	0.9	0.9	0.9	0.9	0.5	1.0
Cloud and Moisture Imagery (unitless)	1.0	0.8	0.9	0.9	0.9	NA	0.5	1.0
Air Temperature: Profiles (K)	0.5	0.8	0.9	0.9	0.9	0.9	0.5	1.0
Total Precipitable Water (mm)	1.0	0.8	0.7	0.7	0.9	NA	0.5	1.0
Land Surface Temp (K)	1.0	0.8	0.9	0.9	0.7	NA	0.5	1.0
Snow Cover (%)	1.0	0.8	0.9	0.9	0.7	NA	0.5	1.0
Snow Depth (m)	1.0	0.8	0.9	0.9	0.7	NA	0.5	1.0
Snow Grain Size (mm)	1.0	0.8	0.9	0.9	0.7	NA	0.5	1.0
Cloud Top Temperature (K)	1.0	0.8	0.9	0.9	0.7	NA	0.5	1.0
Precip Rate/Snowfall Rate (mm/hr)	0.5	0.8	1.0	1.0	0.9	0.7	0.5	1.0
Cloud Base Height (km)	1.0	0.8	0.9	0.9	0.9	NA	0.5	1.0

*** Current Geophysical Variable Need**