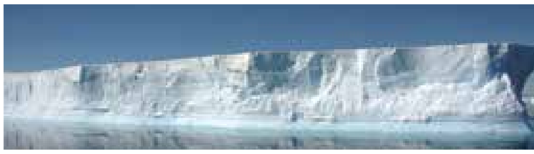
GEO Task US-09-01a:

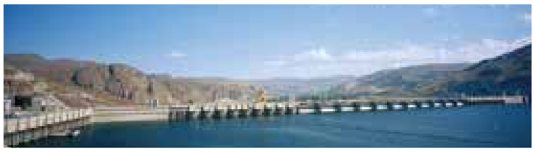
CRITICAL EARTH OBSERVATION PRIORITIES

Precipitation Data Characteristics and User Types







GROUP ON
EARTH OBSERVATIONS

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Report prepared by Battelle Memorial Institute

GEO US-09-01a Web Site:
http://sbageotask.larc.nasa.gov

The Applied Sciences Program in the Earth Science Division of the NASA Science Mission Directorate commissioned and sponsored this study. Lawrence Friedl oversaw the activity as the Task Lead for the Group on Earth Observations Task US-09-01a.[1]

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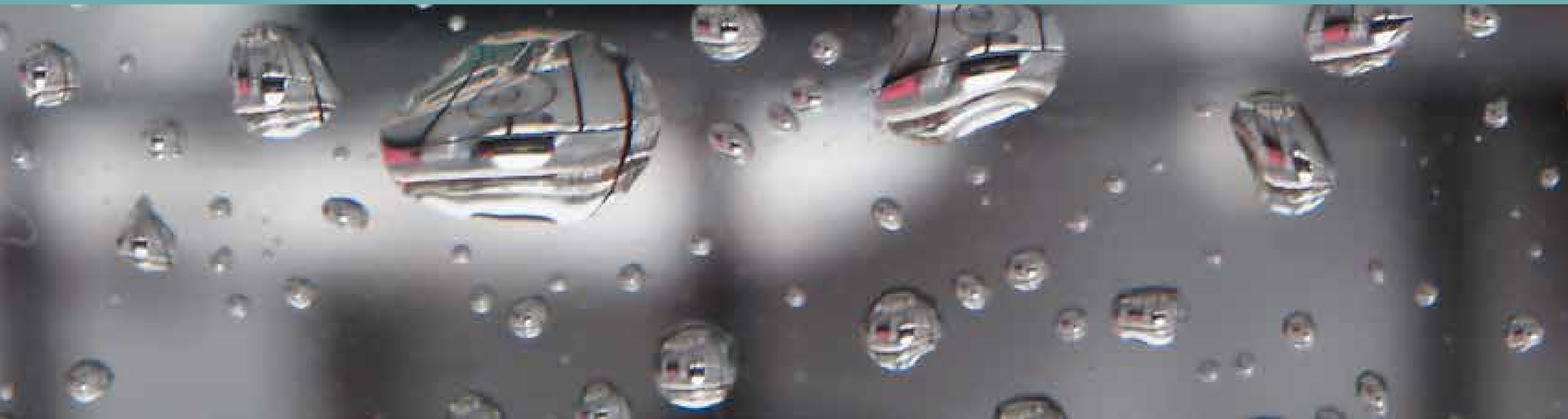
1 Task US-09-01a refers to a task in a former GEO Work Plan structure. In the GEO Work Plan 2012–2015, this study supports numerous Tasks and Components, such as *Building a User-Driven GEOSS* (ID-04) and all the *Information for Societal Benefits* tasks.



Preface

Precipitation is a critical Earth-observation priority for all of the Group on Earth Observation's (GEO) nine Societal Benefit Areas. This document presents the results of an in-depth study by a GEO Task Team to assess the specific observation characteristics needed for precipitation across user types.

This assessment of precipitation data user needs stemmed from GEO Task US-09-01a. First released in 2010 with an update in 2012, the US-09-01a Task report analyzed and presented the critical Earth observations priorities common to many of the societal benefit areas. The task involved a meta-analysis of existing documents that numerous countries and organizations produced regarding Earth observations needs. The five highest-ranked observations were Precipitation, Soil Moisture, Surface Air Temperature, Land Cover, and Surface Wind Speed.

The US-09-01a report includes a finding that, while precipitation was the unanimous top priority, the specific information needs about precipitation likely varied across users in the Societal Benefit Areas. The report recommends that GEO "gather information and engage users on specific characteristics of the priority Earth observations, especially Precipitation." The Task Team responded to that recommendation, and this document presents precipitation parameter characteristics and needs across user types.

This report describes the Task Team's process, data compilation, analysis, and results. The Task Team examined both users and uses. While the team did not conduct a formal "needs assessment," the team evaluated needs by user types as well as by observation characteristics.

The information in this report represents a resource for the GEO community and can support many more activities within GEO. The results and characteristics can allow GEO member countries and participating organizations to assess the availability of precipitation data across the users they serve and represent. In addition, GEO can use this information in analyses of available precipitation observations through the Global Earth Observation System of Systems (GEOSS) or possible user-oriented investment opportunities.

Numerous people and organizations contributed to this activity. On behalf of the Task Team, we especially want to thank and applaud Erica Zell, Adam Carpenter, and Stephanie Weber, from Battelle Memorial Institute, who conducted the analysis and produced this report. We appreciate the input from all the people, GEO Communities of Practice, and other groups they consulted. We want to acknowledge the GEO Integrated Global Water Cycle Observations theme team, particularly Rick Lawford, Sushel Unninayar, and George Huffman, for their consultation and thoughtful review of this report. Finally, I want to thank the task coordinator, Amy Jo Scarino.

I welcome you to visit *http://sbageotask.larc.nasa.gov* for all the reports related to Task US-09-01a and the follow-on assessments and analyses.

Lawrence A. Friedl
Task Lead, GEO Task US-09-01a

Table of Contents

List of Tables

List of Figures

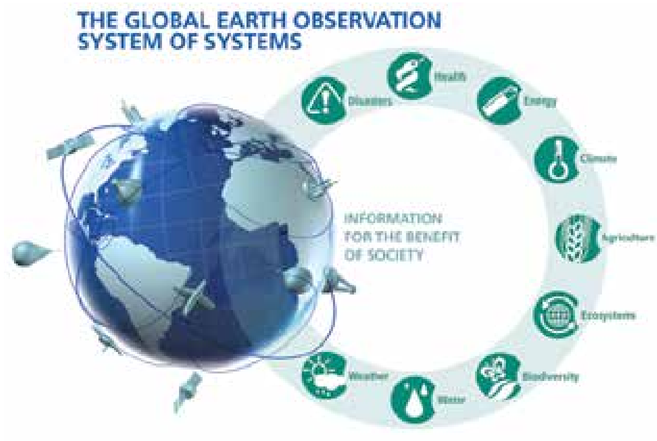
Executive Summary

The Group on Earth Observations (GEO) is an intergovernmental organization working to improve the availability, access, and use of Earth observations to benefit society. GEO focuses on Earth observations for nine Societal Benefit Areas (SBA): Agriculture, Biodiversity, Climate, Disasters, Ecosystems, Energy, Health, Water, and Weather.

An activity under GEO known as Task US-09-01a examined critical Earth observation priorities common to many of the GEO SBAs. Drawing on over 1,700 publicly available documents, the Task identified and produced an overall ranking of 152 critical Earth observation parameters. The five highest-ranked observations were Precipitation, Soil Moisture, Surface Air Temperature, Land Cover, and Surface Wind Speed. The Task Team released a report in 2010 with an updated edition in 2012.

The US-09-01a report included a finding that, while precipitation was the unanimous top priority, the specific information needs about precipitation likely varied across users in the societal benefit areas. The report recommends that GEO "gather information and engage users on specific characteristics of the priority Earth observations, especially Precipitation."

This follow-on report presents the analysis and results generated in response to that recommendation, conveying observation parameter characteristics needed for precipitation across User Types.



Precipitation

Precipitation data, which should be understood to include not only the raw data but also products and information derived from them, serve a wide variety of users and applications. For example, users can range from large hydrometeorological services monitoring and forecasting weather to health officials anticipating outbreaks of disease to private-sector insurance specialists helping farmers manage risk.

Precipitation is measured via rain gauges, ground-based radars, and satellites, among other sensors and platforms. Overall, many users rely on precipitation data from sources such as historical records, near-real-time measurements, and forecasts.

Method and Approach

The Task Team focused on the observation characteristics needed by users of precipitation data. The team conducted a literature review and engaged with GEO Communities of Practice and other organizations, such as the World Meteorological Organization (WMO), to assess users' needs.

To facilitate analysis, the Task Team identified 27 User Types of precipitation information, with examples that include Meteorologists, Natural Resource Managers, Risk Assessors, Utility Operators, Scientists, and Water Resource Managers. The team looked specifically at precipitation data users' needs in terms of spatial resolution, temporal resolution, latency (timeliness), and accuracy.

The Task Team took special care to ensure that "needs" and "wants" were accurately categorized, employing the WMO Rolling Review of Requirements (RRR) system of classifying needs into the following three levels:

- **Threshold:** The minimum need to be met to ensure that data are useful.
- **Breakthrough/Optimum:** The level for significant improvement for the targeted application.[1]
- **Goal:** The ideal need above which further improvements are not necessary.

Analysis, Results, and Findings

The Task Team identified that the spatial resolution needs for precipitation data range from 300 square meters (m^2) to 50 square kilometers (km^2). Many users need temporal resolutions of less than 1 hour, while other users need only daily and sub-daily data. The most common need for latency is users needing data within 0.3 hours (18 minutes) or less.

Accuracy needs are reported in a variety of units depending on the specific precipitation parameter (e.g., rate versus accumulation). Accuracy needs also vary depending on the magnitude of the observation (e.g., light rain versus heavy rain). Thus, accuracy does not lend itself well to summarization across multiple precipitation parameters. In general for precipitation rate, most sources indicated a need for accuracy between 1.0 and 0.1 millimeters per hour (mm/h).

Consultations for this task highlighted that users' needs can vary widely depending upon the application and that the uses may evolve with advances in understanding and modeling.[2]

Table ES-1 shows the median values of Breakthrough/Optimum needs by User Type. Based on the discussion of accuracy above, Table ES-1 excludes accuracy.

1 WMO refers to this level as Breakthrough/Optimum. "Optimum" is used in the context of a cost-benefit perspective.

2 For example, some Climatologists routinely run regional climate models at a 10- to 15-km resolution. Thus, the median value of the 50-km horizontal resolution precipitation data listed in Table ES-1 may not be best suited for the regional climate model context.

Table ES-1. Summary of User Needs by User Type

User Type*	Median of Breakthrough/Optimum Values		
	Horizontal Resolution (km)	Temporal Resolution (hr)	Latency (hr)
Atmospheric Scientists	25.0	1.0	3.0
Meteorologists	5.0	1.0	0.5
Climatologists	50.0	4.0	24.0
Hydrologists	1.0	1.0	0.2
Geo-hazards and Disasters Scientists	1.0	1.0	0.6
Biologists/Ecologists and Natural Resource Managers	1.0	1.6	0.1
Agricultural Planners	7.5	10.0	30.2
Forestry Managers	0.3	24.0	N/A
Water Resources Managers	1.0	1.0	0.3
Fishery Managers**	0.3	24.0	N/A
Recreation and Tourism Managers**	0.3	18	N/A
Commerce Managers**	15.0	0.5	0.1
Transportation Managers	1.0	0.2	0.1
Land User Planners**	0.3	18	N/A
Construction/Building Engineers**	0.3	18	N/A
Food Security Professionals/Development Practitioners	0.5	24.0	N/A
Telecommunications Operators	1.0	0.2	0.2
Risk Managers/Assessors	1.0	0.3	0.2
Energy and Other Utility Planners/Operators	6.1	1.0	0.1
Environmental Regulators and Responders	0.6	0.1	0.1
Ocean and Coastal Emergency Managers**	0.3	18	N/A
Wildfire Monitors and Responders	0.3	24.0	0.02
Security and Defense Planners and Responders	2.0	360	N/A
Journalists	1.0	0.3	0.2

* User Types are grouped roughly by Functional User Category. The User Types of Public Health Researchers/Officials, Satellite Remote Sensing Specialists, and Education Professionals are excluded due to a lack of information on their needs.

** Indicates that values for this User Type represent all need types because Breakthrough/Optimum values were not specified in the literature reviewed.

N/A = No data were available in the literature reviewed.

The Task Team also conducted an analysis to identify sets of users who had similar data needs as well as data characteristics that would satisfy broad groups of users, including the following examples:

- For **spatial resolution**, the team found that there is a broad range of users with spatial (horizontal) resolution needs for precipitation data on the order of 1 km^2 or less (down to 300 m^2). These users tend to be involved in hydrology, disaster planning and response, food security, operations of infrastructure and business, and detailed natural resource mapping.
- For **temporal resolution**, the Task Team found that the finest temporal resolution precipitation data (0.1–0.5 hours) are needed by users involved in transportation, commerce, communication, risk management, and environmental/disaster response.
- For **latency**, the Task Team found that 11 of 27 User Types (41 percent of User Types) need data in less than 0.3 hours (18 minutes), with Wildfire Monitors and Responders having the most stringent need (1 minute).

For precipitation observations, the team classified the 27 User Types into five Functional User Categories: Scientists, Resource Managers, Engineers/Utility Operators, Emergency Managers, and Social Users. The analysis showed patterns in terms of resolution and latency needs that distinguish Functional User Categories from one another. For example, Emergency Managers tend to require the highest spatial resolution data, while Scientists have the coarsest spatial resolution data needs.

A broad range of users reported that precipitation dataset continuity, sharing, and communication are also critical issues. In addition, the team noted that the data needs of users are not universally well-documented. In particular, the needs of users with operational decision-making responsibilities, those in the private sector, and social users (e.g., journalists and news media) are less well-documented in publicly available literature.

Recommendations

Despite the importance of precipitation data, the Task Team found that sharing of precipitation data is somewhat hindered. The team therefore recommends that efforts to enable sharing of precipitation data would be a beneficial activity for GEO to address.

In addition, the team recommends that GEO should consider and emphasize both spatial and temporal continuity in the design of GEOSS and in any observation gap analyses to assess and enhance GEOSS. The Task Team notes that continued engagement with groups familiar with Earth observations is critical.

Given precipitation's importance, GEO can use this information in analyses of precipitation observations available through GEOSS to serve needs across the User Types. Similarly, GEO can analyze gaps and identify priority, user-oriented investment opportunities. The team encourages GEO to use this study to determine further actions to improve precipitation observations, analysis, and data-exchange systems.

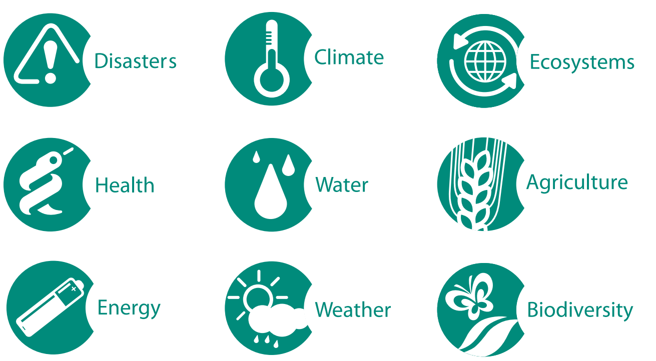
GEO can also use this study as a productive example of an approach to gather and analyze specific observation characteristics within and across User Types. The Task Team provides the following recommendations for detailed studies of other priority observation parameters identified through GEO Task US-09-01a:

- GEO should focus outreach efforts on groups lacking clearly documented needs in order to characterize those needs and help them understand the benefits of Earth observations.
- GEO should consider conducting studies of users' needs that examine more than one observation in isolation in order to reflect the holistic use of Earth observations.

Finally, the Task Team recognizes that this report is in many ways a starting point for GEO. The report serves as a resource for the GEO community and can support many more related activities. GEO member countries and participating organizations can use the results and characteristics in this report to assess precipitation data availability among the users they serve and represent and to identify ways to increase societal benefits.

1.0 Introduction

The Group on Earth Observations (GEO) is an intergovernmental organization working to improve the availability, access, and use of Earth observations to benefit society. GEO coordinates efforts to build a Global Earth Observation System of Systems (GEOSS). GEOSS builds on national, regional, and international observation systems to provide coordinated Earth observations from thousands of ground, airborne, in situ, and space-based instruments. GEOSS's implementation is focused on nine areas of societal benefit, listed below.



An activity under GEO known as Task US-09-01a established and conducted a process to identify critical Earth observation priorities within each individual GEO Societal Benefit Area (SBA) and then those common to many of the SBAs. The task focused on compiling and analyzing information on observation parameters from a representative sampling of publicly available reports, documents, and other materials that many countries and organizations produced. The task addressed all observation needs articulated in the materials—ground, airborne, in situ, and space-based; it also sought needs across a full spectrum of User Types associated with each SBA.

Overall, the activity drew on over 1,700 publicly available documents and involved over 170 advisory group members. The task identified and produced an overall priority ranking of 152 critical Earth observation parameters. The five highest-ranked observations were Precipitation, Soil Moisture, Surface Air Temperature, Land Cover, and Surface Wind Speed. The Task Team released a first edition in 2010 with an updated second edition in 2012; they are available on the task Web site *http://sbageotask.larc.nasa.gov.*

In the report, precipitation was the unanimous top priority—all GEO Societal Benefit Areas identified precipitation as a priority. The primary finding of the report stated the following:

> **Precipitation Reigns the Cross-SBA Analysis.** Precipitation is, by far, the highest-ranked Earth observation need across the societal benefit areas. All 4 prioritization methods ranked Precipitation the highest. Precipitation observation needs expressed in the SBA reports included amount, frequency, duration, information on extreme events, and information on liquid, solid, and mixed phase. While the specific information needs about Precipitation may vary across users for the SBAs, it was unanimous that Precipitation observations are the highest priority.[1]

The report also provided recommendations, including some for suggested follow-on activities based on the results. The first recommendation stated the following:

> **Gather information and engage users on specific characteristics of the priority Earth observations, especially Precipitation.** The Task Team originally sought to gather information about specific characteristics of the needed observations; however, there was insufficient information in the documents. Since there are several priority observations common to many SBAs, the specific characteristics of these common observations should be assessed for each SBA. As part of this effort, the Task Team recommends that [GEO] engage users in

1 Group on Earth Observations, *Task US-09-01a: Critical Earth Observation Priorities* (second edition, 2012), p. 50.

the relevant SBAs for the priority observations to solicit information from them on parameter characteristics and specific uses.[2]

The US-09-01a Task Lead and set of analysts formed a new Task Team to look specifically at precipitation data users' needs in terms of spatial resolution, temporal resolution, accuracy, and latency (timeliness). This follow-on report presents the results of the Task Team's in-depth assessment across User Types of the observation characteristics needed for precipitation.

Precipitation

A diverse range of users and applications utilize precipitation data, derived products, and information (hereinafter, "data"). Precipitation is measured via rain gauges, ground-based radars, and satellites, among other sensors and platforms. Many users rely on precipitation data from sources such as historical records, near real-time measurements, and forecasts.

Users of precipitation data include large hydrometeorological entities that monitor and forecast weather events, health officials who forecast malaria outbreaks, and private sector insurance specialists who help farmers manage risk. Users have specific needs for precipitation data in terms of the spatial resolution or proximity to a given location, the temporal resolution, the accuracy, and the timeliness of data delivery (latency). Understanding the diversity and commonality of these user needs can help inform the design of precipitation monitoring and data dissemination systems. In addition, documenting user needs can support fostering connections of users with similar needs and highlight related issues of dataset continuity and access.

Precipitation is well-recognized as a critical Earth observation parameter. The measurement of precipitation continues to be the focus of many organizations and international endeavors. For example, the International Precipitation Working Group (cosponsored by the World Meteorological Organization [WMO] and the Coordination Group for Meteorological Satellites) focuses on operational-and-research-satellite-based quantitative precipitation measurement issues and challenges. The Committee on Earth Observation Satellites' (CEOS) Precipitation Constellation provides an international framework to coordinate the continued advancements of multisatellite global precipitation products for research and applications. Collectively, a coordinating observing system such as GEOSS seeks to improve the availability, resolution, and accuracy of precipitation measurements.

Follow-on Task

In this follow-on assessment of the observation characteristics needed for precipitation across User Types, the Task Team built on the information gathered from the document-based approach of the original US-09-01a report. As described within the report, the team engaged with organizations and user groups to assess the necessary characteristics of precipitation observations. The primary purpose of the analysis was to identify key User Types for precipitation data, compile information on the needed characteristics of precipitation observations for a wide range of users and applications, and articulate commonalities in needs.

This analysis also served as a prototype for collecting user needs for a given observation. The team evaluated the approach to identify lessons for GEO's pursuit of additional in-depth assessments of other observations across User Types.

This report summarizes the methodology, results, findings, and conclusions of the analysis. Section 2 describes the methods, including the literature review, consultations, and data collection. Section 3 presents the results of the data analysis on users, applications of precipitation data, and the observation-characteristic needs by and across User Types. Section 4 discusses major findings, and Section 5 presents conclusions and recommendations.

A References section lists the documents that the Task Team reviewed and consulted. Appendix A contains details on the user group consultations conducted. Appendix B provides example uses of precipitation data organized by User Type. Appendix C contains tables summarizing users' needs for the precipitation data.

The GEO Task US-09-01a Web site provides access to the reports and materials related to the task and is available at *http://sbageotask.larc.nasa.gov.*

2 GEO, *Critical Earth Observation Priorities,* p. 54.

2.0 Methods

This section describes the approach and methodology to collect and analyze the information. The Task Team designed the analysis to leverage existing Task US-09-01a results and contacts and to draw upon the numerous organizations, working groups, and studies that have examined precipitation needs. The three major phases were (1) the literature review, (2) the user group and organization consultations, and (3) the data compilation and analysis. Each phase is detailed below. There was some overlap and iterative activities between the phases.

2.1 Literature Review

In this phase, the Task Team identified documents to collect and extract information on the users, uses, and required precipitation observation characteristics. The Task Team gathered information from the following sources:

- **References cited in Task US-09-01a individual SBA reports:** Individual SBA reports identified the source documents used in those analyses, such as major studies, workshop reports, needs assessments, and other relevant resources.
- **Additional references:** The Task Team identified reference documents through online searches and consultations with user groups (see below).

Collectively, the Task Team extracted information on specific, quantitative user needs for precipitation data from 49 references to support this analysis. From each reference, the Task Team extracted the following (where specified):

- The users and/or uses of precipitation observations,
- The required horizontal spatial resolution or spacing of monitors,
- The required vertical resolution,
- The required temporal resolution (frequency of observations),
- The required latency (time between observation and reporting), and
- The required accuracy and/or precision.

In addition, the Task Team noted any specific details of the users or uses, relevant measurement technologies or datasets, and any qualitative description of needs that did not fit into the categories listed above.[1] The Task Team compiled the information on precipitation users' data needs and prepared a summary for the team's outreach to user groups.

1 For example, the Task Team collected needs for both liquid- and solid-precipitation measurements, notating each need as appropriate. For solid precipitation, the Task Team focused only on solid precipitation rates, rather than on user needs for related parameters, such as snow-water equivalency or snow-pack depth, to remain within allotted project resources. Cryosphere users' needs are a topic unto itself that is beyond the scope of this analysis. This scope boundary does not impact the results of precipitation user-needs analysis, since observations such as snow pack are distinct from the needs for falling precipitation data.

2.2 User Group and Organization Consultations

The Task Team conducted consultations to identify documents that specify users' needs for precipitation data and to obtain any context relevant for analyzing users' needs. To maximize the reach of the consultations, the Task Team focused on existing user groups and GEO Communities of Practice (CoP). The Task Team contacted a total of 15 user groups/CoPs, and it pursued meetings or teleconferences with all organizations that responded with interest. As background, the Task Team provided an overview of Task US-09-01a and the follow-on precipitation study. The Task Team also provided a presentation and written narration to facilitate the conference calls. Table 1 lists the groups with which the Task Team consulted. Appendix A contains a list of the attendees for each call.

Table 1. Groups Consulted for Identification of Precipitation Data Needs

User Group/Community of Practice
Famine Early Warning System Network (FEWS NET) Team
GEO Air Quality CoP [2]
GEO Cryosphere CoP
GEO Integrated Global Water Cycle Observations CoP
Insurance and International Finance [3]
International Precipitation Working Group (IPWG)

The Task Team conducted all consultations via teleconference. Each session lasted approximately 1 hour, with a brief presentation followed by a discussion. For most consultations, a self-identified set of members and the group leader participated. Some of the attendees provided viewpoints from multiple organizations (e.g., their employing agency and an international workgroup in which they participate). In total, the Task Team talked with approximately 31 people over a series of eight consultation teleconferences. In addition to receiving direct input from persons on the phone call, the Task Team requested that attendees submit any references to document the needs identified. The Task Team routinely received additional references to review and contacts to pursue based on the consultations. The Task Team reviewed all documents received for relevancy, extracted the appropriate information on user needs, and followed through on the most relevant contacts for additional consultations.

2.3 Data Compilation and Analysis

In the data compilation and analysis phase, the Task Team synthesized the results from the literature review and user group consultations. The Task Team tabulated the detailed characteristics of users' precipitation data needs and standardized the information across terminology and units. The Task Team analyzed the information, as described in the following subsections, to identify major themes, trends, and commonalities in need across uses and User Types.

2.3.1 Analysis by User Type

The Task Team compiled a master list of users and uses identified through the literature review and consultations. The team used this list to standardize the classification of users and uses and to examine the observation needs by User Type.

2 This group thanked the Task Team for the presentation, yet the Task Team never received follow-up comments from the group.

3 The Task Team was not able to identify any user groups or formal CoPs under GEO that focused on insurance or international finance. The team did follow up with this collection of individuals per the recommendation of the IPWG.

In some cases, the source documents themselves classified some users' precipitation data needs into different levels of need (e.g., a minimum resolution needed versus a resolution that could provide breakthroughs in the field). For example, a document might articulate the characteristics for the minimum resolution needed as well as the resolution for breakthroughs in the field. The Task Team recorded and classified all stated user needs into one of three categories: Threshold, Breakthrough/Optimum, and Goal. The team used the WMO classification schema of user needs from the WMO's Rolling Review of Requirements:

- **Threshold:** The minimum need to be met to ensure that data are useful.
- **Breakthrough/Optimum:**[4] The level for significant improvement for the targeted application.
- **Goal:** The ideal need above which further improvements are not necessary.

Where documents or consultations did not explicitly or contextually indicate the level of need, the Task Team treated the need as a midlevel "Breakthrough" need. In this way, the Task Team identified three sets of needs for the analysis. To help prevent the category or classification labels from introducing bias, the Task Team looked at the distinct categories of needs separately and also looked at the entire range of needs. Each table in Section 3 (Results) clarifies which sets of needs are included in the particular analysis.

2.3.2 Analysis by Precipitation Observation Characteristic

To help identify natural groupings or patterns in the set of all needs, the Task Team also analyzed the needs by certain observation characteristics: horizontal resolution, temporal resolution, latency, and accuracy. This approach enabled the Task Team to identify sets of users with similar needs (e.g., users needing precipitation observations on an hourly timescale) as well as to identify data characteristics that would satisfy broad groups of users.

4 WMO refers to this level as Breakthrough/Optimum. "Optimum" is used in the context of a cost-benefit perspective.

2.4 Spatial Coverage

The Task Team did not specifically address spatial or domain coverage of precipitation datasets in this study because spatial coverage was judged as too highly application-dependent. The team's consultations highlighted that not all datasets are needed on a global scale. The same user may require data at different resolutions depending on whether the data are for global, regional, or local applications. For example, applications using climate prediction and weather forecasting models need global coverage at certain resolutions while regional and local coverage need much higher spatial and temporal resolutions.

Further, while most resource managers require high spatial and temporal resolution data at the local/subregional scales, other resource managers also need data on global scales. Such global-scale needs of resource managers can support monitoring and early-warning systems (e.g., floods, droughts, food shortages) that provide information internationally and guide international assistance programs. Thus, the complexity of the issue of spatial or domain coverage proved beyond the scope of the endeavor.

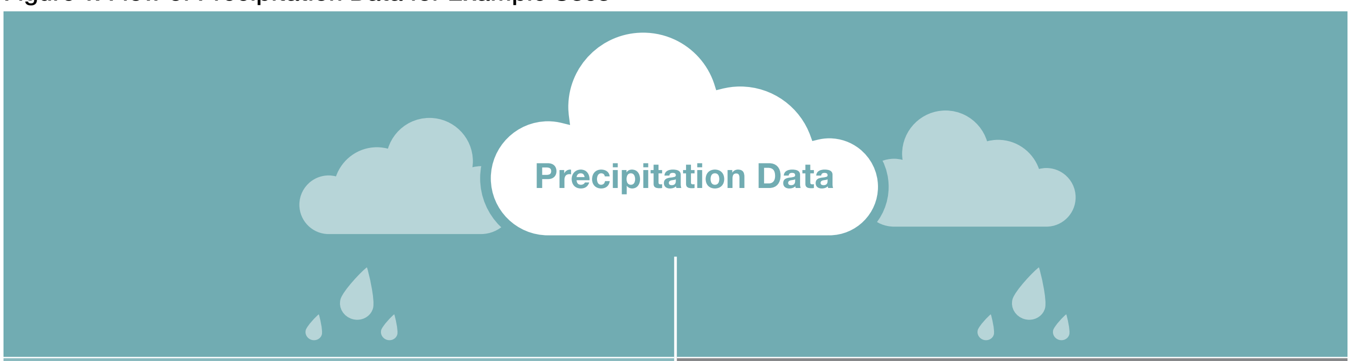
3.0 Results

This section presents the results of the Task Team's data collection and analysis. First, Section 3.1 describes the users and uses of precipitation data encountered in the literature review and consultations. Next, Section 3.2 presents a summary of users' precipitation data needs organized according to User Type. Finally, Section 3.3 identifies trends in specific data-need characteristics (such as temporal resolution) across User Types.

3.1 Users and Uses

The Task Team found that some users apply precipitation measurements directly for their application or decision while other users require either forecasted precipitation or other derived products. Such derived products (e.g., a flood forecast) rely wholly or in part on observations of precipitation. Figure 1 depicts representative uses of precipitation data.

Figure 1. Flow of Precipitation Data for Example Uses



Use in Models for Planning/Forecasts		Direct Uses for Monitoring, Research, and Social Uses	
NWP Models	**Other Models**	**Monitoring**	**Planning/Designing**
Short-term forecasts Seasonal outlooks Climate projections	Stream-flow forecasts Energy load forecasts Food security analysis	Disease outbreaks Crop yield assessment Disaster response Index insurance triggers Wildfire management	Stormwater management planning Land use planning/building design
Planning/Operating	**Planning/Operating**	**Scientific Research**	**Social Uses**
Aviation routing Agricultural management Risk assessment Sustainable development	Flood warnings Energy grid operations Food aid distribution	Water cycle analysis Biological models	Education applications Journalists/media uses

Table 2. Example Functional User Categories and User Types of Precipitation Data

Functional User Category	User Type
	Atmospheric Scientists
Scientists	Meteorologists
	Climatologists
	Hydrologists/Cryosphere Scientists
	Satellite Remote Sensing Specialists
	Geohazards and Disasters Scientists
Resource Managers	Biologists/Ecologists and Natural Resource Managers
	Public Health Researchers/Officials
	Agricultural Planners
	Forestry Managers
	Water Resources Managers
	Fishery Managers
Engineers/Utility Operators	Recreation and Tourism Managers
	Commerce Managers
	Transportation Managers
	Land User Planners
	Construction/Building Engineers
	Food Security Professionals and Development Practitioners
Emergency Managers	Telecommunications Operators
	Risk Managers/Assessors
	Energy and Other Utility Planners/Operators
	Environmental Regulators and Responders
	Ocean and Coastal Emergency Managers
	Wildfire Monitors and Responders
	Security and Defense Planners and Responders
Social Users	Education Professionals
	Journalists

The Task Team classified users by sector to best reflect the characterizations encountered in the literature of users and facilitate quantitative analysis. These sectors represent the primary application area of each class of users, such as natural resources management, agriculture, weather prediction, or health. Table 2 shows the 27 User Types that the Task Team identified. This list is not exhaustive, yet it does cover the major User Types that the Task Team found in the literature and through user-group consultations. The Task Team found that the 27 User Types fall roughly into five broad User Categories according to function: Scientists, Resource Managers, Engineers/Utility Operators, Emergency Managers, and Social Users.[1] Table 2 groups the User Types loosely adjacent to a continuum of these broad Functional User Categories. Some User Types may align with more than one Functional User Category; this report lists the User Type according to the predominant functional category that the team found in the literature.

Some users are several steps removed from actual precipitation measurements on the "information chain." For instance, domestic policymakers employ precipitation data indirectly when they create stormwater laws and regulations, based on the analysis of their staff or supporting government agencies. Policymakers often rely on the analysis of relevant precipitation data by specialists such as Hydrologists. The same applies to the use of precipitation information at the international policy level such as by the Intergovernmental Panel on Climate Change (IPCC). The IPCC relies on an international group of scientists to assess the reliability of global climate models by comparing the results of climate simulations to observations of precipitation (among other parameters such as temperature). Table 2 omits users such as these policymakers who are several steps removed from actual precipitation measurements on the "information chain."

Some of the listed User Types routinely make decisions in an operational context.[2] As highlighted in the study consultations, users of data with operational decision-making responsibilities are not necessarily in organized groups that establish detailed user needs. Rather, such users simply use the best available data, as do social users who are not likely to have specific data needs. Also, data users in the private sector may not have publicly documented their data needs or sources for proprietary reasons. Thus, the approach illustrated in Table 2 may underrepresent such operational and social users due to limited documentation and engagement on their data needs. To an extent, some organizations efforts, such as WMO's Rolling Review of Requirements, may capture the needs of such operational and social users.[3]

Appendix B contains specific uses of precipitation data that the Task Team identified through the literature review and consultations.

1 The term "Social Users" refers to users whose function is to communicate information through public media, spread general knowledge, and/or build capacity for future users of information (i.e., through training and education).

2 The term operational context refers in this report to users with day-to-day decision-making responsibilities to manage a rapidly changing resource, support a business, or monitor and respond to an emergency in near-real-time, rather than conduct historic analysis or long-term planning activities.

3 WMO's Rolling Review of Requirements is used as an example; this study did not assess the comprehensiveness of the WMO RRR database or consultation process.

3.2 Characterizing Needs by User Type

The Task Team characterized the needs for precipitation observations according to User Type. The Task Team used these types to identify typical needs and ranges of needs in terms of horizontal spatial and temporal resolution, latency, and accuracy.

In the literature and through consultations, the Task Team encountered five major variations of the term "precipitation observations," as follows:

- **Precipitation:** Rate and intensity of either liquid only or solid/liquid precipitation, with units of depth/time.
- **Accumulation:** Total precipitation over the temporal resolution, with units of depth.
- **Solid/Snowfall Precipitation:** Rate and intensity, with units of depth/time.
- **Precipitation Detection:** Binary response (yes/no, presence/absence), with probability of detection and false-alarm ratios specified for accuracy.
- **Precipitation Type:** Categories indicated, such as rain or snow.

The Task Team considered all five of these precipitation observation types collectively in the analysis of users' required resolution and latency (except where noted). The Task Team made this choice because there is relatively little variation between the average data needs for each precipitation type (see Appendix C, Table C-2). Also, examining users' needs without regard to precipitation observation type provides a larger set of data with which to work. The needs of individual users for specific precipitation observation types, such as solid/snowfall precipitation, are still critical and should be assessed further for any monitoring system design. In fact, because accuracy is specific to the units of the observation/measurement, accuracy was analyzed separately for each precipitation observation type.

Of the 27 User Types identified through the literature review and consultations, quantitative information on the User Type's observation characteristic needs was available for 24 of the 27.[4]

Table 3 summarizes the major findings of precipitation data user needs by User Type. This table shows the median values of the Breakthrough/Optimum needs identified according to User Type. Median values are shown in this table to minimize the effect of outliers. Consultations for this task highlighted that specific user needs can vary widely depending upon the application, and users' needs evolve as advances in understanding and models evolve.[5] Refer to Appendix C for a complete listing of the average, median, minimum, and maximum of Breakthrough/Optimum needs.

4 The Task Team did not find sufficient quantitative information for Public Health Researchers/Officials, Satellite Remote Sensing Specialists, or Education Professionals. The team excluded these three categories from the quantitative analysis. They do not appear in Tables 3–7.

5 For example, some Climatologists routinely run regional climate models at a 10- to 15-km resolution. Thus, the median value of the 50-km horizontal resolution precipitation data listed in Table 3 may not be best suited for the regional climate model context.

Table 3. Summary of User Needs by User Type

User Type*	Median of Breakthrough/Optimum Values		
	Horizontal Resolution (km)	Temporal Resolution (hr)	Latency (hr)
Atmospheric Scientists	25.0	1.0	3.0
Meteorologists	5.0	1.0	0.5
Climatologists	50.0	4.0	24.0
Hydrologists	1.0	1.0	0.2
Geohazards and Disasters Scientists	1.0	1.0	0.6
Biologists/Ecologists and Natural Resource Managers	1.0	1.6	0.1
Agricultural Planners	7.5	10.0	30.2
Forestry Managers	0.3	24.0	N/A
Water Resources Managers	1.0	1.0	0.3
Fishery Managers**	0.3	24.0	N/A
Recreation and Tourism Managers**	0.3	18	N/A
Commerce Managers**	15.0	0.5	0.1
Transportation Managers	1.0	0.2	0.1
Land User Planners**	0.3	18	N/A
Construction/Building Engineers**	0.3	18	N/A
Food Security Professionals and Development Practitioners	0.5	24.0	N/A
Telecommunications Operators	1.0	0.2	0.2
Risk Managers/Assessors	1.0	0.3	0.2
Energy and Other Utility Planners/Operators	6.1	1.0	0.1
Environmental Regulators and Responders	0.6	0.1	0.1
Ocean and Coastal Emergency Managers**	0.3	18	N/A
Wildfire Monitors and Responders	0.3	24.0	0.02
Security and Defense Planners and Responders	2.0	360	N/A
Journalists	1.0	0.3	0.2

* User Types are listed in the same order as Table 2, grouped roughly by Functional User Category. The User Types of Public Health Researchers/Officials, Satellite Remote Sensing Specialists, and Education Professionals are excluded due to a lack of information on their needs.

** Indicates that values for this User Type represent all need types, because Breakthrough/Optimum values were not specified in the literature reviewed.

N/A = No data were available in the literature reviewed.

Horizontal Spatial Resolution

The Task Team identified some general patterns with regard to spatial resolution:

- The Task Team found that there is a **broad range of users** with spatial (horizontal) resolution needs for precipitation data on the order of 1 km^2 or less (down to 300 m^2). These users tend to be involved in hydrology, disaster planning and response, operations of infrastructure and business, food security, and detailed natural resource mapping.
- The Task Team found a **second set of users** with spatial (horizontal) resolution needs on a scale of 5–10 km^2; these users focused on agricultural and meteorological uses, along with commercial and utility management/operations.
- The Task Team found a **third set of users** with spatial (horizontal) resolution needs on the order of 25–50 km^2; these users included Climatologists and Atmospheric Scientists who tend to conduct regional or global analyses.

Temporal Resolution

The Task Team identified some general patterns with regard to temporal resolution:

- Users' required temporal resolution of precipitation data **ranges from 0.1 hours (6 minutes) to sub-daily and daily**.[6]
- The **finest temporal resolution** precipitation data (0.1–0.5 hours) are needed by users involved in transportation, commerce, communication, risk management, and environmental response.
- Scientists and utility operators fall into a **second tier** with temporal resolution needs of 1–4 hours.
- Natural resource managers and planners primarily fall into a **third tier** with temporal resolution needs of 10–24 hours.

6 There is an outlier need of temporal needs which is 360 hours (15 days) for Security and Defense Planners and Responders.

Latency

The Task Team identified some general patterns with regard to latency:

- Required latency was indicated for only 16 of the 27 (59 percent) of the User Types.
- 11 User Types need **data in less than 0.3 hours** (18 minutes), with Wildfire Monitors and Responders having the most stringent need (1 minute).
- On the **far end of the spectrum** in terms of latency, Climatologists and Agricultural Planners report that 24–30 hour latency is acceptable.

The Task Team notes that it is possible that "timely data"[7] (e.g., within 1 hour) is not a high priority for the 11 User Types not reporting on latency. In addition, consultations highlighted that some of the sources indicating particularly high latency needs (or other characteristic needs, for that matter) may refer to only a subset of situations in which latency is particularly important. It is also possible that only users with unmet latency needs tend to report them. In such a case, the reported latency needs would be biased towards quick turnaround needs.

Examination by Functional User Category

The Task Team assessed users' needs by Functional User Category to identify any patterns related to the different tasks and timeframes of each Functional User Category. The results are shown in Table 4. The Functional User Category analysis eliminates summary statistics of users' needs that were based on relatively few data points, thus making the results more robust. For example, there were only two references in the literature to quantitative precipitation characteristic data needs for Telecommunications Operators. (The average number of references in the literature to quantitative precipitation characteristic data needs was 13; Table C-1 lists the number of data points for each User Type). Grouping the Telecommunications Operators with others in the Engineers/Utility Operators Functional User Category provides a broader look at data needs for other users performing similar functions.

Figure 2 provides a graphical look at users' needs by Functional User Category. For this figure, the Task Team analyzed all need levels (Threshold, Breakthrough/Optimum, and Goal) together. This approach provides a comprehensive

7 The Task Team acknowledges that this term does not have a consensus definition.

treatment of the data collected. Overall, this analysis shows that there is a pattern distinguishing the needs of distinct Functional User Categories from one another. This pattern holds true for all three observation characteristics examined quantitatively (horizontal spatial resolution, temporal resolution, and latency). For example, these items were specific to users' needs for spatial resolution:

- When considering mean values, Scientists tend to require coarse spatial resolution data.
- By contrast, Emergency Managers tend to require the highest spatial resolution.
- Resource Managers and Engineers/Utility Operators have precipitation data needs falling between Scientists and Emergency Managers, in terms of spatial resolution.

Similarly, Emergency Managers are at the high end of temporal resolution needs and latency needs compared to the other Functional User Categories.[8]

Table 4. Summary of User Needs by Functional User Category

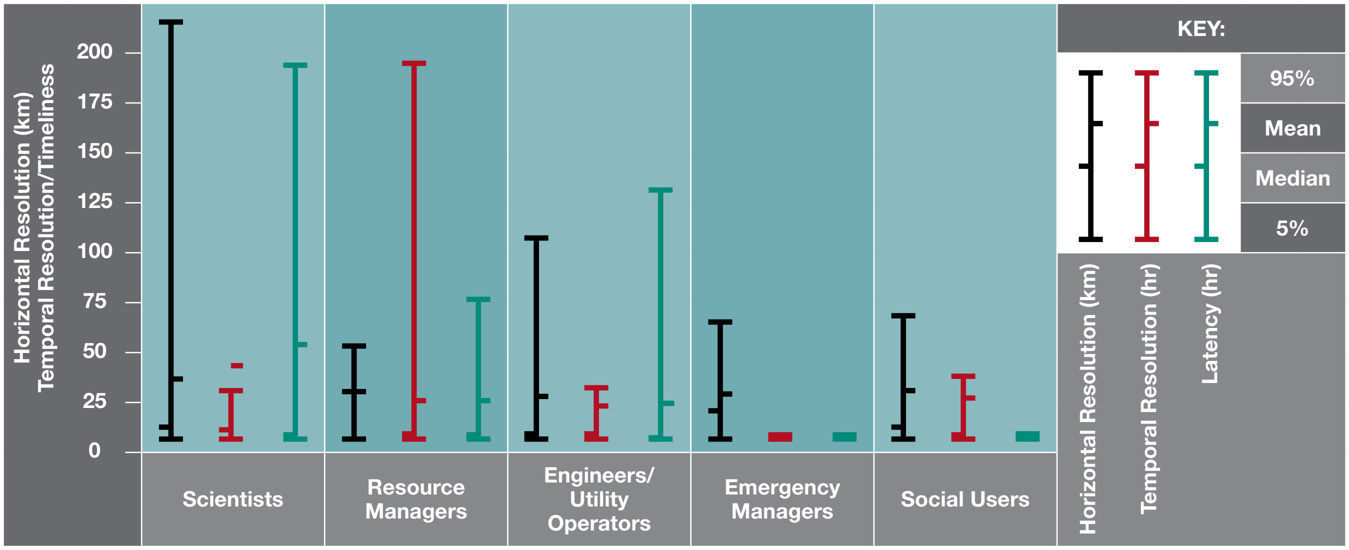
Functional User Category	Horizontal Resolution			Temporal Resolution			Latency		
	Median* (km)	Finest** (km)	Coarsest*** (km)	Median* (hr)	Finest** (hr)	Coarsest*** (hr)	Median* (hr)	Soonest** (hr)	Latest*** (hr)
Scientists	5	0.00005	1000	1	0.017	720	0.5	0.017	1440
Resource Managers	3	0.00005	500	1	0.017	720	0.5	0.017	720
Engineers/Utility Operators	1	0.1	111	0.63	0.017	240	0.13	0.017	170
Emergency Managers	0.63	0.1	100	0.25	0.017	720	0.017	0.017	1
Social Users	1	1	50	0.25	0.25	1	0.17	0.083	1

*Median values represent Breakthrough/Optimum needs only.

**Finest/soonest values represent all Breakthrough/Optimum and Goal needs (whichever is a lower number for a given Functional User Category).

***Coarsest/latest values represent all Breakthrough/Optimum and Threshold needs (whichever is a higher number for a given Functional User Category).

Figure 2. User Needs by Functional User Category



8 These conclusions reference mean values of all three needs levels.

3.3 Characterizing Needs by Observation Characteristic

The Task Team assessed needs according to observation characteristic (e.g., spatial resolution) to identify commonalities in need across User Types. The following discussion highlights the findings for each observation characteristic, and it gives examples of observation characteristics that would meet the calculated median needs of various sets of users. This analysis presents results for each observation characteristic separately.[9] The letter designations for User Types are unique to each table.

Spatial Resolution

Table 5 shows groupings according to natural breaks of users' needs for horizontal spatial resolution of precipitation data.

Table 5. Groupings of User Types by Horizontal Resolution Needs

Horizontal Resolution*	User Types
0.3–0.6 km	(A) Construction/Building Engineers (B) Environmental Regulators and Responders (C) Fishery Managers (D) Food Security Professionals and Development Practitioners (E) Forestry Managers (F) Hydrologists (G) Land User Planners (H) Ocean and Coastal Emergency Managers (I) Recreation and Tourism Managers (J) Wildfire Monitors and Responders
1.0–2.0 km	(K) Biologists/Ecologists and Natural Resource Managers (L) Geohazards and Disasters Scientists (M) Journalists (N) Water Resources Managers (O) Risk Managers/Assessors (P) Security and Defense Planners and Responders (Q) Telecommunications Operators (R) Transportation Managers
5.0–15 km	(S) Agricultural Planners (T) Commerce Managers (U) Energy and Other Utility Planners/Operators (V) Meteorologists
25–50 km	(W) Atmospheric Scientists (X) Climatologists

*Based on values shown in Table 3 (principally median Breakthrough/Optimum values).

9 The Task Team acknowledges that meeting the information needs of users involves consideration of the ensemble of horizontal spatial resolution, temporal resolution, timeliness (latency), and accuracy needs.

As shown in Table 5, 1.0-km horizontal resolution precipitation data would meet median needs as follows:

- Threshold values of three of the User Types (Environmental Regulators and Responders [B], Forestry Managers [E], and Wildlife Monitors and Responders [J]) listed for 0.3–0.6-km (Breakthrough/Optimum) needs
- Threshold values of other User Types (denoted K through X) in the table
- Breakthrough/Optimum needs of eight User Types (denoted K through R) listed for 1.0–2.0-km resolution in the table
- Breakthrough/Optimum needs of an additional eight User Types (denoted S through X) who are satisfied with slightly coarser scale (5.0–50 km) data
- Goal values of three User Types (Commerce Managers [T], Meteorologists [V], and Climatologists [X]) out of the 15 User Types specifying Goal values[10]

As a second example, 0.3-km horizontal resolution precipitation data would meet median needs as follows:

- Threshold value needs of all 24 User Types listed in the table
- Breakthrough/Optimum needs of all 24 User Types listed in the table
- Goal values of 5 User Types (Hydrologists [F], Water Resources Managers [N], Commerce Managers [T], Meteorologists [V], and Climatologists [X]) out of the 15 User Types specifying Goal values

A given user would find their needs met with a product that is at least as fine as (or much coarser than) their stated need. However, users that require only coarse-resolution data would benefit from an aggregated data product (at a coarse resolution) because such product would reduce data volumes and processing times with unnecessarily-fine-scale data. (The same concept applies to temporal resolution, for which overly-fine-timescale data could be a hindrance to users only needing more coarse temporal resolution.)

10 Not all User Types had associated Goal values specified.

Temporal Resolution

Table 6 shows groupings according to natural breaks of users' needs for temporal resolution of precipitation data.

Table 6. Groupings of User Types by Temporal Resolution Needs

Temporal Resolution*	User Types
0.1–0.5 hr	(A) Environmental Regulators and Responders (B) Transportation Managers (C) Telecommunications Operators (D) Risk Managers/Assessors (E) Journalists (F) Commerce Managers
1.0–4.0 hr	(G) Atmospheric Scientists (H) Meteorologists (I) Hydrologists (J) Geohazards and Disasters Scientists (K) Water Resources Managers (L) Energy and Other Utility Planners/Operators (M) Biologists/Ecologists and Natural Resource Managers (N) Climatologists
10–24 hr	(O) Agricultural Planners (P) Recreation and Tourism Managers (Q) Land User Planners (R) Construction/Building Engineers (S) Ocean and Coastal Emergency Managers (T) Forestry Managers (U) Fishery Managers (V) Food Security Professionals and Development Practitioners (W) Wildfire Monitors and Responders
360 hr (15 days)	(X) Security and Defense Planners and Responders

*Based on values shown in Table 3 (principally median value for Breakthrough/Optimum needs).

As shown in Table 6, 1.0-hour temporal resolution precipitation data would meet median needs as follows:

- Threshold values of all User Types (denoted A through X) in the table
- Breakthrough/Optimum needs of the eight User Types (denoted G through N) listed for 1.0–4.0-hour resolution in the table
- Breakthrough/Optimum needs of the additional 10 User Types (denoted O through X) who are satisfied with slightly coarser scale (10 hour–15 day) data
- Goal values of 11 User Types (Risk Managers/Assessors [D], Biologists/Ecologists and Natural Resource Managers [M], Climatologists [N], Agricultural Planners [O], Recreation and Tourism Managers [P], Land User Planners [Q], Construction/Building Engineers [R], Ocean and Coastal Emergency Managers [S], Fishery Managers [U], Food Security Professionals and Development Practitioners [V], and Security and Defense Planners and Responders [X]) out of the 16 User Types specifying Goal values

Latency

Table 7 shows groupings according to natural breaks of users' needs for latency for the 16 User Types that specified a goal.

Table 7. Groupings of User Types by Latency Needs

Latency*	User Types
0.017–0.25 hr (1–15 min)	(A) Biologists/Ecologists and Natural Resource Managers (B) Commerce Managers (C) Energy and Other Utility Planners/Operators (D) Environmental Regulators and Responders (E) Hydrologists (F) Journalists (G) Risk Managers/Assessors (H) Telecommunications Operators (I) Transportation Managers (J) Wildfire Monitors and Responders
0.3–0.6 hr (18–36 min)	(K) Geohazards and Disasters Scientists (L) Meteorologists (M) Water Resources Managers
3.0 hr	(N) Atmospheric Scientists
24–30 hr	(O) Agricultural Planners (P) Climatologists

*Based on values shown in Table 3 (principally median Breakthrough/Optimum values).

As shown in Table 7, precipitation data that are made available within 0.3 hours (18 minutes) of observation would meet median latency needs as follows:

- Threshold values of 4 (Energy and Other Utility Planners/Operators [C], Risk Managers/Assessors [G], Telecommunications Operators [H], Wildfire Monitors and Responders [J]) out of the 10 User Types whose Breakthrough/Optimum values are less than 0.3 hours
- Threshold values of others User Types (denoted K through P) in the table
- Breakthrough/Optimum needs of the three User Types (denoted K through M) listed for 0.3–0.6-hour latency in the table
- Breakthrough/Optimum needs of the additional three User Types (denoted N through P) who are satisfied with a longer latency (3.0–30 hours)
- Goal values of two User Types (Agricultural Planners [O] and Climatologists [P]) out of the seven User Types specifying Goal values

Accuracy

The Task Team found that users specified their accuracy needs in a few ways. Some specified accuracy in units that matched the unit of the observation parameter (e.g., mm/h for precipitation rate), and some specified accuracy as a percentage of an actual value. This report includes both. The following lists users' accuracy needs of the five observation parameter types (see Section 3.2):[11]

- Precipitation
    - Most sources indicated 1.0 to 0.1 mm/h.
    - Reported values range from 10 mm/h (a minimum Threshold for some Meteorologists and Climatologists) to 0.05 mm/h (a Breakthrough/Optimum or Goal value for some Climatologist and Biologists/Ecologists/Natural Resource Managers).
    - Some sources indicated a need for data within 10 percent of the actual monthly total.
- Accumulation
    - Most sources indicated 2.5 to 0.25 mm (for a median temporal resolution of 3 hours, as listed in Table 6).
- Solid/Snowfall Precipitation
    - Most sources indicated 1.0 to 0.1 mm/h.
- Precipitation Detection
    - Many users indicated probability of detection (hit rate) and false alarm rate (HR/FR) as 50/50 and 95/10, with some extreme values such as 99/2.
- Precipitation Type
    - Many users noted a need for three to six classes (unspecified) of precipitation-type data.

11 Values for accuracies are listed from looser accuracy to tighter accuracy. With accuracies, a smaller number implies a tighter accuracy.

Several items are worth noting regarding the reporting of accuracy needs. A users' statement of a needed spatial resolution of precipitation data often reflects a need to have data that are accurate to a given degree for a point or area of interest. Such needs for a stated spatial resolution then are related to the spatial variation in precipitation patterns. Many users do not explicitly report a required accuracy. Instead, users report a required spatial resolution. In consultations, several users highlighted that higher spatial or temporal resolution data are only useful if the accuracy is not degraded in the process of increasing the resolution. The issue of bias versus random error is closely associated with the issue of accuracy but was not explicitly addressed in most of the documents reviewed.

Users discussed technologies such as satellite microwaves for highly accurate measurements. Users also noted that infrared measurements on geostationary satellites sacrifice accuracy (by 20–30 percent) but increase resolution compared to microwaves. Users cited the benefits of merged products (from multiple data sources) to optimize the balance between accuracy and resolution. Different applications may prioritize one characteristic over the other. For instance, users who need to make flash flood predictions prioritize high temporal resolution and may sacrifice the accuracy of fully quality-controlled data in exchange for timely data (e.g., 5-minute temporal resolution). Longer-latency datasets permit the use of additional data, including monthly analyses of precipitation gauge data, for quality control and calibration. These longer-latency datasets, however, may not meet users' needs for latency.

Finally, many sources that cited precipitation needs distinguished accuracy according to precipitation rate. In part, consultations indicated this distinction acknowledges that precipitation varies nonlinearly over several orders of magnitude, meaning that no single absolute or proportional threshold applies equally in all cases. The Task Team notes that this distinction also likely reflects the varying accuracy of current precipitation sensors by precipitation rate. Some technologies are less accurate for lower rain rates. This illustrates how user needs may inherently reflect the limits of existing technology rather than representing an ideal data need independent of the data collection technology.

4.0 Findings

This section discusses major findings from the analysis. The findings present information to aid in interpreting the results. They highlight key qualitative aspects to users' needs for precipitation observations, such as data continuity and data sharing.

4.1 Users' Needs and Wants

The team found that a majority of the user groups and organizations consulted discussed "needs versus wants" for the observation characteristics. For example, needs might convey a minimum useful resolution, and wants might be a resolution that would greatly improve an analysis or decision.

The team found that there are sensitivities about needs and wants by both data providers and data users. As highlighted particularly by data-providing organizations engaged as part of user groups, the range between users' needs and wants can be considerable. In addition, user groups noted that ensuring that "needs" and "wants" are accurately classified will increase the robustness of cross-sectoral comparisons of data needs. This issue has implications for how users document their needs, and how studies (such as this one) collect and analyze user needs, as discussed in Section 2.3.1.

In this study, the Task Team found that users' need statements (without specification of need level) tended toward the "Breakthrough/Optimum" level in the WMO classification system. The Task Team reached this finding by comparing unspecified need levels to users' needs that were self-classified according to need level.

Some User Types defined a wide range of needs, from Threshold minimum needs to ideal objectives that may be unobtainable with today's technology. Looking across Functional User Categories in Table 4, the Scientists category (and to a lesser extent the Resource Managers category) had a wide range between Threshold (coarsest/latest) and Goal (finest/soonest) needs; other Functional User Categories had a comparatively narrow range.[1] The implications are that users (beyond Scientists and Resource Managers) may need to be consulted and encouraged to think more broadly about the utility and benefits of higher-resolution, higher-accuracy, and/or more real-time data.

4.2 Data Continuity

Data continuity refers to the continued acquisition and availability of data that the user considers to be sufficiently consistent. Consistency can include the collection methods (whether in situ, airborne, or satellite), collection timeframes, processing algorithms, or other characteristics of the dataset that make it suitable for long-term analysis without introducing significant bias or error into such analysis. Data continuity can refer to both spatial and temporal continuity.

The Task Team found that precipitation data users—from climate researchers to operational food security forecasters—need historical datasets of precipitation with a high degree of continuity. The need for continuity of measurement was expressed in the consultations, and the need was confirmed by multiple source documents. This need included satellite-derived precipitation data that are uniformly processed and reprocessed (temporal continuity) when new algorithms are developed. Historical datasets with comparable data are important for establishing long-term trends and relationships in a variety of application areas. Datasets that are collected with different methodologies or processed with different algorithms inhibit or complicate such analyses.

In consultations, users noted that much precipitation data are never reprocessed after the fact when new algorithms are developed, creating problems in comparing older and newer measurements. Users noted that the establishment of a minimum standard for data continuity is important. Users also noted that satellite datasets cannot by themselves provide long-term and fine-scale estimates.

1 Note that Table 4 distinguishes among Threshold, Breakthrough/Optimum, and Goal needs. Conversely, Figure 2 does NOT distinguish among Threshold, Breakthrough/Optimum, and Goal needs, and thus does not inform this particular finding.

Thus, the team found there is a potential for creative combinations of satellite and other data from surface observations and numerical models to meet data continuity and coverage needs. The Task Team did not review literature or ask user groups about observations beyond precipitation. However, the Task Team presumes that the need for continuity and reprocessing is likely applicable to other priority Earth observations as well.

As identified through the documents reviewed and consultations conducted, example applications requiring long time series of precipitation data are as follows:

- Calculation of daily climatological statistics for a variety of applications requires datasets of approximately 30 years.
- Analysis of global climate change ideally requires datasets of approximately 100 or more years.
- Famine early-warning systems require a minimum of approximately 30 years of data, with 50–60 years of data preferred.
- Agricultural index insurance requires datasets of approximately 20 years or more to determine risk and the location-specific relationship between yield and rainfall.

The need for continuity also referred to ground-based data that are collected with consistent methodologies and properly maintained equipment (spatial and temporal continuity). Users, such as food security specialists and those in the insurance industry, noted that the coverage and density of rain gauges in many parts of the world, such as much of Africa, are inadequate.

While the Task Team undertook this study to identify users' needs without regard to measurement technology, the importance of quality-controlled ground-based stations for creating long-term precipitation datasets and other purposes, such as validating satellite data, was repeatedly noted in consultations.

4.3 Data Sharing and Communication

Both the consultations and the literature review highlighted the problem of withholding precipitation data (for both satellite-derived and ground-based data). For example, the Task Team found that in some countries in Africa a wealth of precipitation data exists, yet the data are not fully digitized or otherwise shared. However, the consultations and the literature review also provided examples of innovative data sharing and communication.

Thus, the relevance of these findings suggests that limitations of precipitation data are not just related to the monitoring systems themselves—they are also related to the sharing and communication of data to users.

With regard to ground-based data, sharing of precipitation data worldwide is one of the Action Goals stated in a 2009 Global Climate Observing System report. This report notes that "Major progress has been made in the submission of precipitation data from national networks to the international data centres, with 175 countries having delivered precipitation data…although the target of 20% increase in reception compared to 2004 has not been achieved. Significant gaps in coverage remain, and more prompt submission of data is also required."[2] Two specific examples are as follows:

- "Access to precipitation data for China is problematic despite a sound weather monitoring infrastructure…. 160 weather stations exchange data globally through the World Meteorological Organization, but access to both historical daily weather data and real-time daily data is considered confidential and is thus very difficult."[3]
- In Mexico there are "764 automated weather stations constructed by Fundación PRODUCE, the private rural producers' association," which are not included in a shared GEOSS pool of data.[4]

2 World Meteorological Organization, "Progress Report on the Implementation of the Global Observing System for Climate in Support of the UNFCCC, 2004–2008" (Geneva, Switzerland: 2009), p. 26.

3 International Fund for Agricultural Development and World Food Programme, "The Potential for Scale and Sustainability in Weather Index Insurance for Agriculture and Rural Livelihoods" (Rome, Italy: 2010), p. 47.

4 Ibid.

The Task Team also made a key finding regarding data sharing within the cryosphere community. The cryosphere community (among others) echoed the concern that many precipitation observations are considered to be sensitive or related to national security due to water rights and other issues. The cryosphere community emphasized that much of the concern is that precipitation data, once observed and collected, are not being shared and archived properly.

With regard to timely flow/communication of precipitation data, the IPWG noted a particular challenge. Specifically, the IPWG highlighted that data policies that embargo data flow for a day or longer are problematic. With relation to this study, Table 7 shows the precipitation data latency needs of 16 User Types. Fourteen of these 16 User Types need data within 3 hours or less based on median Breakthrough/Optimum values. Hence, a day or longer embargo of data, referenced by the IPWG, precludes meeting the latency needs of 88 percent of User Types for which the Task Team identified precipitation data latency needs. Only the Agricultural Planner and Climatologist User Types would likely be unaffected by a data embargo of a day or longer.

Consultations indicated that there also are issues related to data-exchange costs (pricing) even if precipitation datasets are, in principle, available without restriction for international data exchange. In general, the use of weather data is sensitive to pricing considerations. Based on this finding, the team suggests that GEO include examination of data-exchange costs in potential future investigations of data sharing.

As GEO seeks to address the highlighted challenges of data sharing and communication, the team offers that GEO should consider examples of innovative methods that were emphasized in the documents that the Task Team reviewed for this study. For example, an International Fund for Agricultural Development (IFAD) report noted an innovative data-sharing application in India:

> The dissemination of data via mobile phone SMS [short message service] communications has become more and more important in helping farmers minimize crop losses and understand the exact nature and magnitude of weather risks. In Punjab, for example, timely forecasts via SMS messages gave farmers the information they needed to prevent major frost losses and save on irrigation costs.[5]

From the consultations, additional examples of potential means for data communication are the visualization systems enabled by advances in data-processing technology. One such system that is accessible via the Internet is the NASA Goddard Earth Sciences Data and Information Services Center's Geospatial Interactive Online Visualization ANd aNalysis Infrastructure, or GIOVANNI.[6] Such examples of data communication highlight the need to tailor information and access systems for the targeted users, taking latency needs and available channels of communication into account.

4.4 Documentation of Precipitation Data Users' Needs

The Task Team found that the data needs of users are not universally well-documented. In particular, the needs of users with operational decision-making responsibilities, those in the private sector, and social users such as the media are not as well-documented in publicly available literature. From our Task Team's experience in arranging consultations with user groups, users with operational decision-making responsibilities, those in the private sector, and social users do not tend to be engaged in the Earth observation community and associated communities of practice where users' needs are identified.

Table C-1 lists users' needs by User Type and includes the number of data points on precipitation data characteristic needs that the Task Team found for each User Type. Each document included in the analysis provided one or more sets of data characteristics needed by a User Type; thus, the number of documents addressing each User Type is less than or equal to the listed number of data points.[7]

5 Ibid., p. 46.

6 NASA Giovanni is available at *http://disc.sci.gsfc.nasa.gov/giovanni/overview/index.html.*

7 Some documents discussed various needs for different subsets of User Types. Other documents describe a single set of needs that applies to multiple User Types.

As listed in Table C-1, Meteorologists had the most data points (66), indicating relatively good documentation of this User Type's needs for precipitation data. Five User Types (Forestry Managers, Telecommunications Operators, Environmental Regulators and Responders, Security and Defense Planners/Responders, and Journalists) had 3 or fewer data points. In addition, there were three User Types (Public Health Researchers/Officials, Satellite Remote Sensing Specialists,[8] and Education Professionals) for which no quantitative data was available on specific precipitation data needs. The team suggests that GEO focus on identifying and documenting some of these relatively undocumented user needs for precipitation data.

4.5 Additional Needs

The consultations conducted by the Task Team highlighted several additional considerations and needs with regard to precipitation data, including the following selected examples:

- The need for a gap analysis that identifies specific improvements required in observing systems, data collection, analysis, and data integration systems, as well as data-exchange systems and datasets. For example, consultations identified the need for identifying the requirements of future space-based missions that will distinguish between solid and liquid precipitation with a focus on latitudes higher than the tropics.
- The need for more feedback on the uses of and user needs for integrated precipitation products where in situ data are merged with satellite data or data-assimilation products.
- The need for availability and user assessments of other Earth observations (e.g., soil moisture) that are used concurrently with precipitation data by various applications.
- The need for availability and user assessments of global versus regional versus local data, and the impact of user needs on the design of observing systems.
- The potential need for user education about the sources and characteristics (including limitations) of the precipitation data that are currently available.

8 The Task Team acknowledges that Satellite Remote Sensing Specialists are a combination data provider/data user and do not necessarily have specific precipitation data "user needs" parallel to other User Types.

5.0 Conclusions and Recommendations

Understanding users' needs for Earth observation data is a challenging task, yet one that is critical for achieving societal benefit from Earth observations. As the original US-09-01a report indicated, precipitation data are especially important to many users and SBAs.

The Task Team found that the data needs of users are not universally well-documented. In particular, the needs of users with operational decision-making responsibilities, those in the private sector, and social users are not well-documented. The team recommends that GEO plan additional efforts and outreach to these groups to characterize their needs and help them understand the benefits of Earth observations.

At the same time, the Task Team notes that continued engagement with groups familiar with Earth observations is also critical. By drawing on existing documentation of users' needs and conducting multiple consultations, studies, such as this effort, can facilitate increased engagement between the Earth observations provider and user communities.

Beyond the studied dataset characteristics, precipitation dataset continuity and data sharing and communication are critical issues to a broad range of users. However, despite the importance of precipitation data, the Task Team found that the sharing of precipitation data is somewhat hindered. Thus, the team recommends that, given the priority ranking of precipitation across all Societal Benefit Areas, attention and efforts to enable sharing of precipitation data would be a particularly important, beneficial, and fruitful activity for GEO to address.

Similarly, GEO should consider both spatial and temporal continuity in the design of GEOSS and in any observation gap analyses to assess and enhance GEOSS. If GEO were to meet users' precipitation data characteristic needs without addressing issues of continuity and sharing/communication, users' applications of any given precipitation dataset could be limited.

One basic purpose of this endeavor was to test the feasibility of compiling information on User Types, the needed characteristics of precipitation observations for a range of users, and identification of commonalities in need. The approach proved to be feasible and successful, and the approach could be extended to other Earth observation data types. GEO can use this study as a productive example of an approach to gather and analyze specific observation characteristics within and across User Types.

The Task Team provides the following recommendations for detailed studies of other priority observation parameters identified through GEO Task US-09-01a:

- GEO should focus outreach efforts on groups lacking properly documented needs in order to characterize those needs and help them understand the benefits of Earth observations.
- GEO should consider conducting studies of users' needs that examine more than one observation in isolation in order to reflect the holistic use of Earth observations.

Finally, the Task Team recognizes that this report is in many ways a starting point for GEO. The report serves as a resource for the GEO community and can support many more related activities. GEO can also use this study to determine further actions to improve precipitation observations, analysis, and data exchange systems. GEO member countries and participating organizations can use the results and characteristics in this report to assess precipitation data availability among the users they serve and represent and to identify ways to increase societal benefits.

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This list contains all documents from which the Task Team collected quantitative users' needs for precipitation observations. The Task Team reviewed additional documents; however, they are not listed here because they did not include quantitative information about users' needs.

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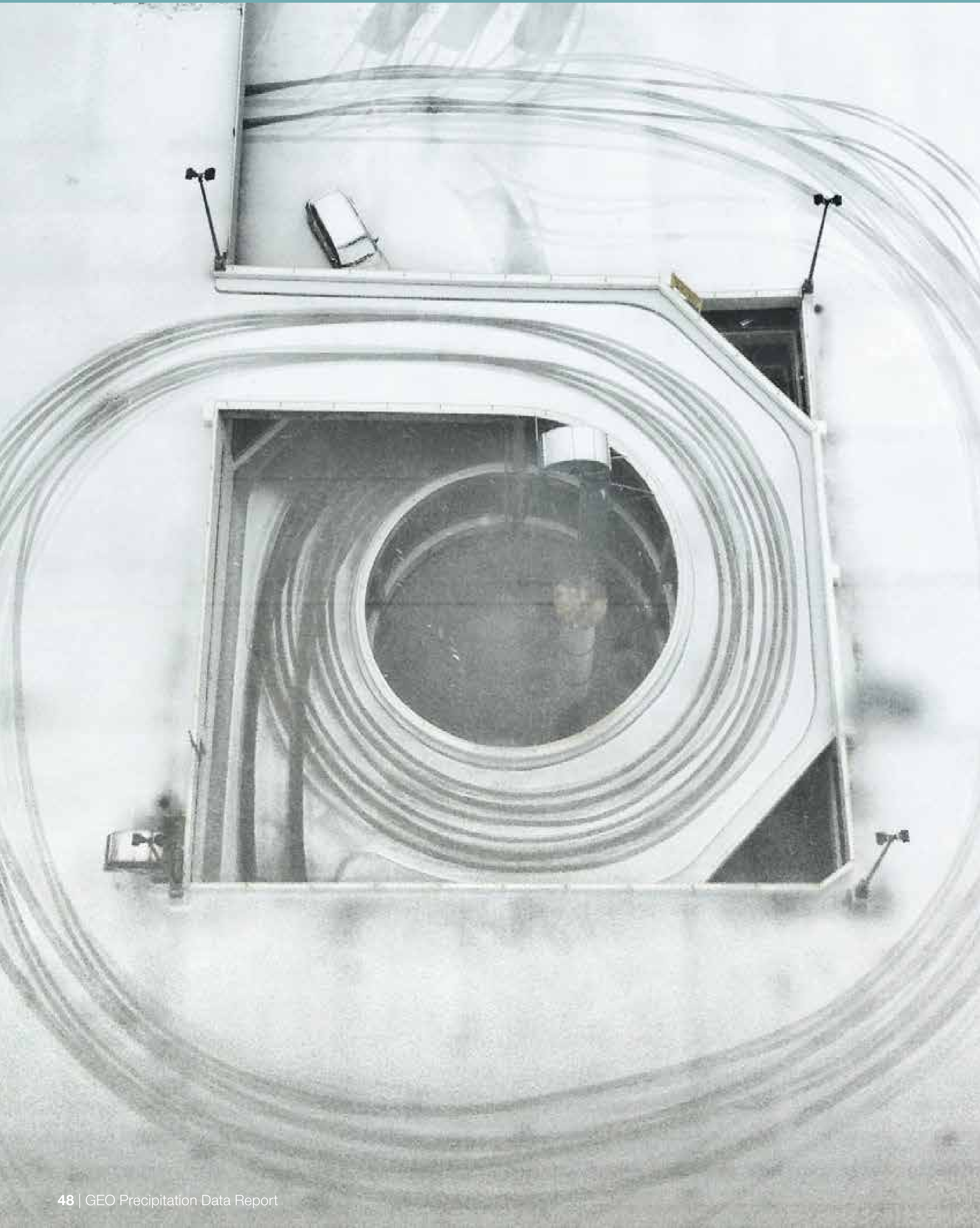


Appendix A: Consultations Conducted

Table A-1. Consultations Conducted

Date	User Group/Community of Practice	Attendees
8/24/2011	GEO Air Quality CoP*	Rudy Husar, Washington University (various others, unknown)
8/29/2011	GEO Cryosphere CoP	Daqing Yang, Environment Canada Jeff Key, University of Wisconsin Barry Goodison, WMO
9/6/2011	International Precipitation Working Group	George Huffman, NASA Goddard Space Flight Center (GSFC) Dalia Kirschbaum, NASA GSFC Rick Lawford, University of Maryland (via separate call)
9/7/2011	International Precipitation Working Group (2nd call)	Paul Joe, Environment Canada Joe Turk, NASA Jet Propulsion Laboratory (JPL) Paul Kucera, National Center for Atmospheric Research (NCAR) Bob Adler, University of Maryland
9/7/2011	Famine Early Warning System Network (FEWS NET) Team	Molly Brown, NASA GSFC Gary Eilerts, U.S. Agency for International Development (USAID) (via e-mail consultation) Jim Rowland, USGS
9/27/2011	Insurance and International Finance**	Marcel Kuettel, Swiss Re Peter Maina, International Finance Corporation Selin Konrat, International Finance Corporation
9/28/2011	GEO Integrated Global Water Cycle Observations CoP	Douglas Cripe, GEO Secretariat Daniel Vila, Instituto Nacional de Pesquisas Espaciais (INPE) (Brazilian National Institute For Space Research) Sushel Unninayar, University of Maryland–Baltimore County Angelica Gutierrez-Magness, National Oceanic and Atmospheric Administration (NOAA)

* This group thanked the Task Team for the presentation, yet the Task Team never received follow-up comments from the group.

** The Task Team was not able to identify any user groups or formal CoPs under GEO that focused on insurance or international finance, but the team did follow up with this collection of individuals per the recommendation of the IPWG.

Appendix B: Example Precipitation Data Uses by User Type

The following discussion highlights specific uses of precipitation data that the Task Team identified through the literature review and consultations. The User Types match those listed in Table 2.

Atmospheric Scientists require precipitation data for applications such as incorporation into atmospheric dispersion, atmospheric chemistry, and air-quality models.

Meteorologists require precipitation data for applications such as numerical weather prediction (regional and global), model analysis, data assimilation, synoptic meteorology, nowcasting, improving the predictability of hurricanes and severe local storms, and assessing snow and ice accumulations and snow avalanche potential. Meteorologists also use precipitation data to inform policy decisions on droughts, flooding, and tropical cyclone hazards, as well as to provide warnings for fishery and coastal zone activities and agricultural works and crop protection.

Climatologists require precipitation data for applications such as climate modeling and verification, global change research, cryosphere research, rainfall over the ocean estimation, seasonal and inter-annual forecasts, sea level rise and loss of coastal land modeling, El Niño Southern Oscillation and Madden-Julian Oscillation analysis, monsoon monitoring, urbanization impact analysis, and inter-decadal climatic fluctuations and trends analysis.

Hydrologists and Cryosphere Scientists require precipitation data for applications such as global and regional water cycle analysis, hydrological risk analysis, cryosphere research, ground-based and satellite data sources assimilation, ocean freshwater budget analysis, stream-flow research, land surface and hydrological modeling, and groundwater recharge.

Satellite Remote Sensing Specialists require precipitation data (from ground-based networks) for applications such as calibrating current sensors and evaluating and improving upon previous generations of sensors for future missions.

Geohazards and Disasters Scientists require precipitation data for extreme events (including landslides, floods, volcano eruptions, and earthquakes), as well as for research, monitoring, planning, and advising disaster response.

Biologists/Ecologists and Natural Resource Managers require precipitation data for applications such as inputs to biological models, terrestrial climate analysis, ecosystems of concern projections, vegetation index research and analysis, animal and habitat tracking (e.g., elephant tracking), and underwater noise estimation.

Public Health Researchers/Officials require precipitation data as one of many inputs to applications such as predicting unusually large numbers of asthma-related visits to hospitals, predicting malaria outbreaks, and more broadly for nowcasting or forecasting diseases and disease vectors (e.g., mosquitoes).

Agricultural Producers, Resource Managers, Technical Advisors, and Agricultural Meteorologists require precipitation data and forecasts (from agricultural meteorologists) for applications such as assessing and predicting crop yields, growing seasons, damage, water needs, and management problems (e.g., pests); understanding water availability for irrigated lands; assessing mechanization options and soil erosion; and conducting drought analysis and forecasting.

Forestry Managers require precipitation data for applications such as assessing and predicting forest growth and health and assessing wildfire risks.

Water Resources Managers require precipitation data for applications such as flash flood monitoring and flood-water runoff modeling, estimating water resource availability for rain-fed and irrigated agriculture, and river and reservoir management.

Fisheries Managers require precipitation data for applications such as the development of warnings for fishing and coastal activities and the assessment of marine and freshwater ecosystems and ecosystem stressors.

Recreation and Tourism Managers require precipitation data for applications such as facilities design and operation, communicating climate and weather information and warnings to tourists, and supporting key sporting events (e.g., the Winter Olympics).

Commerce Managers require precipitation data to support planning and operations broadly, presumably with applications similar to User Types such as Transportation Manager and Risk Manager/Assessor (although the Task Team did not identify specifics with regard to Commerce Manager applications in the documents reviewed for this study).

Transportation Managers require precipitation data for applications such as monitoring and predicting conditions for road transport, aviation, and shipping; designing and constructing transportation systems; planning least-time routing; and preparing ice forecasts for ship navigation and offshore activities.

Land Use Planners require precipitation data for applications such as conducting land resource inventories, assessing and predicting loss of coastal land due to sea level rise, understanding relationships between urbanization and weather/precipitation, and defining the need for design standards (e.g., roof loading and tornado-safe rooms).

Construction/Building Engineers require precipitation data for industry planning and operations at large and for specific applications such as the development of building codes and civil engineering standards and planning and conducting construction on land and at sea.

Example User: Water Resources Manager

Water resource managers at the Mekong River Commission (an intergovernmental agency that works with the governments of Cambodia, Lao People's Democratic Republic, Thailand, and Vietnam on joint management and sustainable development of the Mekong River) use merged satellite/rain-gauge-based forecasts of precipitation (delivered daily during the wet season) in the Flood Forecasting and River Monitoring System.

Food Security Professionals and Development Practitioners require precipitation data for applications such as understanding the water cycle and climate variability trends in support of sustainable development and for food security and famine warnings, utilizing rainfall as an indicator of crop and rangeland condition.

Telecommunications Operators require precipitation data for applications such as understanding operational risks and threats to telecommunications utilities.

Risk Managers/Assessors require precipitation data for applications such as insurance, re-insurance, and micro-insurance risk analysis, including risks from extreme precipitation, flooding, drought, and ice buildup; and for specific applications such as setting and assessing payment trigger values in agricultural index insurance and validating ground-based measurements with satellite measurements for fraud detection. For example, risk managers at Oxfam-America are conducting an index insurance project in Ethiopia that requires precipitation data.

Energy and Other Utility Planners/Operators require precipitation data for applications such as consumption and production planning for electricity, gas, fuel, drainage, and water utilities; designing and operating hydropower plants; and assessing ice buildup on utility structures.

Environmental Regulators and Responders require precipitation data for applications such as designing stormwater control needs and monitoring and responding to pollution events such as oil spills or atmospheric releases.

Ocean and Coastal Emergency Managers require precipitation data for applications such as issuing coastal hazard warnings, informing decisions on sea ice hazards, and informing planning for sea level rise and the loss of coastal land.

Wildfire Monitors and Responders require precipitation data for applications such as monitoring and modeling wildfire potential (including fuel load) and status and for fire management activities (e.g., forecasting wildfire spread and containment).

Security and Defense Planners and Responders require precipitation data for applications such as preparing people and property for extreme events, raising and lowering alert levels, analyzing environmental connections to civil unrest, and for unspecified uses in the intelligence community.

Education Professionals require precipitation data for applications in both formal and informal education and for museums and environmental education.

Journalists require precipitation data for news stories and background and for directly communicating weather conditions, forecasts, and warnings.

Example User: Wildfire Monitors and Responders

Wildfire Monitors and Responders at the Council for Scientific and Industrial Research (CSIR) in South Africa use satellite-based 24-hour accumulations of precipitation in a fire warning product for fire management.

Appendix C: Additional Data Tables of Users' Needs

Table C-1. Users' Needs By User Type (Breakthrough/Optimum Values Except Where Noted)

User Type†	# of data points^	Horizontal Resolution (km)*				Temporal Resolution (hr)*				Latency (hr)*			
		Average	Median	Min	Max	Average	Median	Min	Max	Average	Median	Min	Max
Atmospheric Scientists	6	42	25	0.1	100	1.5	1.0	0.02	3.0	360	3.0	0.02	1080
Meteorologists	66	11	5.0	0.001	100	11	1.0	0.1	240	11	0.5	N/A	168
Climatologists	21	60	50	0.2	200	15	4.0	0.3	168	173	24	N/A	1080
Hydrologists	40	10	1.0	0.005	100	2.7	1.0	N/A	24	86	0.2	N/A	1080
Geohazards and Disasters Scientists	14	6	1.0	0.1	20	3.6	1.0	N/A	24	0.6	0.6	N/A	1.0
Biologists/Ecologists and Natural Resource Managers	4	0.7	1.0	0.1	1.0	6.8	1.6	0.02	24	8.0	0.1	0.02	24
Agricultural Planners	20	13	7.5	0.001	56	44	10	0.5	240	30.2	30.2	30.2	30.2
Forestry Managers	3	0.3	0.3	0.3	0.3	24	24	24	24	N/A	N/A	N/A	N/A
Water Resources Managers	35	2.7	1.0	0.005	11	3.7	1.0	N/A	24	0.4	0.3	0.1	1.0
Fishery Managers∆	8	0.3	0.3	0.1	0.5	106	24	12	720	N/A	N/A	N/A	N/A
Recreation and Tourism Managers	6	0.3	0.3	0.1	0.5	18	18	12	24	N/A	N/A	N/A	N/A
Commerce Managers	6	15	15	5	25	0.5	0.5	0.08	1	0.12	0.09	0.02	0.25
Transportation Managers	5	1.2	1.0	1.0	2.0	0.2	0.2	0.1	0.3	0.1	0.1	N/A	0.3
Land User Planners∆	10	0.3	0.3	0.1	0.5	18	18	12	24	N/A	N/A	N/A	N/A
Construction/Building Engineers∆	7	0.3	0.3	0.1	0.5	18	18	12	24	N/A	N/A	N/A	N/A
Food Security Professionals/Development Practitioners	15	3.2	0.5	0.25	10	89	24	3.0	240	N/A	N/A	N/A	N/A
Telecommunications Operators	2	1.0	1.0	1.0	1.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Risk Managers/Assessors	10	3.3	1.0	1.0	10	9.7	0.3	0.1	24	42	0.2	0.1	168
Energy and Other Utility Planners/ Operators	4	6.1	6.1	1.0	11	0.9	1.0	0.1	1.5	0.1	0.1	0.1	0.1
Environmental Regulators and Responders	3	0.6	0.6	0.1	1.0	0.1	0.1	0.02	0.3	0.1	0.1	0.02	0.1
Ocean and Coastal Emergency Managers∆	7	0.3	0.3	0.1	0.5	18	18	12	24	N/A	N/A	N/A	N/A
Wildfire Monitors and Responders	5	6.8	0.3	0.1	20	16	24	0.02	24	0.02	0.02	0.02	0.02
Security and Defense Planners/ Responders	3	2.0	2.0	2.0	2.0	360	360	0.3	720	N/A	N/A	N/A	N/A
Journalists	2	1.0	1.0	1.0	1.0	0.3	0.3	0.3	0.3	0.2	0.2	0.1	0.3

* The Task Team converted units for display and analysis purposes rather than retain original units reported by users.

N/A = No data available in the literature reviewed.

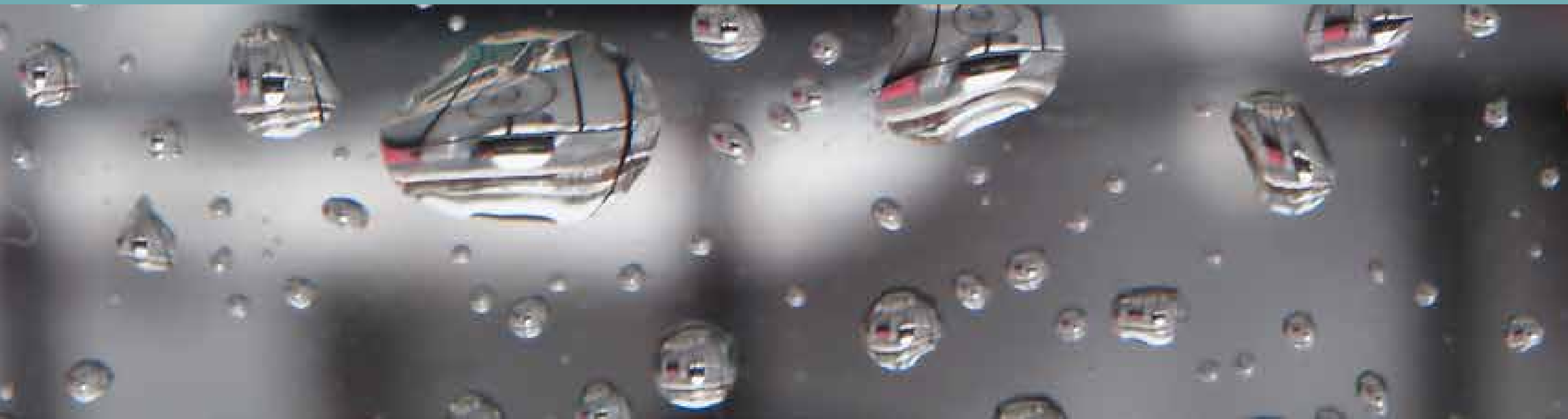
† User Types are grouped roughly by Functional User Category but exclude Public Health Researchers/Officials, Satellite Remote Sensing Specialists, and Education Professionals because of a lack of quantitative data on user needs.

^ Indicates the number of quantitative requirements spelled out for this User Type (equal to or greater than the number of documents that address this User Type, since some documents include multiple needs applicable to the same cross-cutting User Type, such as Meteorologists).

∆ Indicates that values for this User Type represent all need types because Breakthrough/Optimum values were not specified in the literature reviewed.

Table C-2. Summary of User Needs by Observation Parameter

Parameter Class	Median Values		
	Horizontal Resolution (km)	Temporal Resolution (hr)	Latency (hr)
Precipitation	4	1	0.25
Accumulation	10	3	10.5
Solid Precipitation Rate	10	1	0.5
Precipitation Detection	5	1	0.3
Precipitation Type	5	0.75	0.25



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