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# Democratizing Environmental Data via the Model Context Protocol: A Service-Oriented Architecture for Environmental Intelligence

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## Abstract

Advances in Artificial Intelligence (AI), particularly agentic AI, have created opportunities to improve efficiency and accuracy in addressing sustainability and environmental problems. Agentic AIs autonomously plan and execute towards specific goals with minimal or no human intervention; however, accessing environmental data is challenging and requires expertise, due to inherent fragmentation and the diversity of data formats. The Model Context Protocol (MCP) is an open standard that allows AI systems to securely access and interact with diverse software tools and data sources through unified interfaces, reducing the need for custom integrations while enabling more accurate, context-aware assistance. This study introduces WeatherInfo\_MCP, an interface that provides the required expertise to AI agents to access National Weather Service (NWS) data. Built on a Service-Oriented Architecture, the system uses a centralized engine to handle robust geocoding and data extraction, while providing AI agents with simple, independent tools to retrieve weather data from the NWS API. The system was validated through 14 unit tests and 23 comprehensive protocol compliance tests against the MCP 2025-06-18 specification, achieving a 100% pass rate across all categories, demonstrating its reliability when working with AI agents. We also successfully tested our model alongside a memory MCP to showcase its performance in a multi-MCP environment. While in its earliest version, WeatherInfo\_MCP connects to the NWS API, its modular design and compliance with software development and MCP standards facilitate immediate expansion to additional environmental data and tools. WeatherInfo\_MCP is released as an open-source tool to enable broad adoption and further development.

**Keywords:** Model Context Protocol (MCP); Agentic Environmental Monitoring; Interoperable Climate Data; AI-Driven Decision Support Systems; Automated Crisis Response; Service-Oriented Architecture

## 1. Introduction

Weather- and climate-related disasters represent a mounting global challenge, imposing ever-greater costs on societies and threatening more lives each year [1]. The United States was hit by 14 billion-dollar weather disasters in the first half of 2025, causing \$101.4 billion damage [2]. From 1980 to mid-2025, the country suffered more than 417 events exceeding \$1 billion each, with a cumulative loss of over \$3.1 trillion and more than 17,000 lives lost [3]. Globally, the scale is even more dramatic: the World Meteorological

Organization (WMO) reports that the number of weather-related disasters has increased fivefold during the past half-century, primarily due to climate change, population growth in high-risk areas, and improved reporting [4], [5]. Although improved disaster management and early warning systems have reduced fatalities per event, the total exposure and financial toll continue to increase, creating demand for more effective and inclusive resiliency strategies [6].

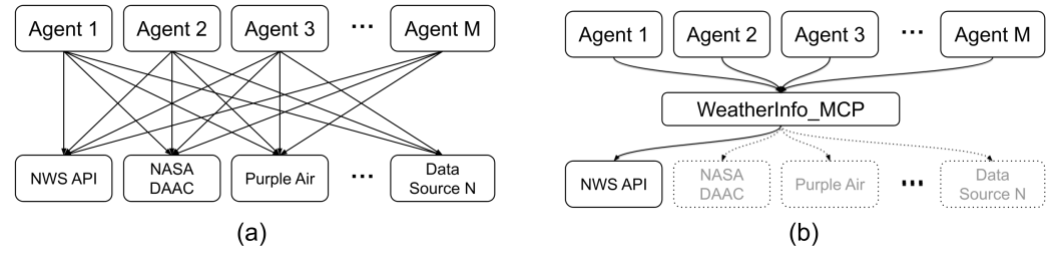
Informing vulnerable groups about weather hazards and their consequences in a timely manner is vital for overcoming these challenges. Culturally appropriate community-led interventions and integration of digital tools are promising avenues for increasing the utilization of interventions [7]. Active, low-cost communication and outreach campaigns have demonstrated substantial value, and further research is needed to optimize disaster response and preparedness activities, such as for heatwaves [8]. Increasingly, programs recognize the need to resolve the interplay between environmental exposure, population sensitivity, adaptive capacity, and behavior as determinants of risk, requiring advances in observational data and individual-scale modeling tools [9].

The recent advancements in artificial intelligence (AI) applications in meteorology is transforming the prediction and communication of environmental risks. Initial advances focused on enhancing forecasting skill and spatial resolution through machine learning, deep learning, and geospatial foundation models [10], [11]. Using techniques such as recurrent neural networks, diffusion models, and transformer-based architectures to analyze large, multimodal datasets, AI-driven methodologies have considerably improved accuracy in predicting environmental variables [12], [13]. The advent of large language models (LLMs) and multimodal AI systems further expands the range of applications to include scenario planning, advanced early warning, and near-real-time risk assessment for decision-makers and the public [14].

Despite this technological progress, significant barriers persist in the mobilization of accurate, actionable information for crisis management [4], [15]. Early warning systems are often closed, lack global reach, and miss relevant risk drivers, which burdens organizations with high costs and time investment [4]. Consistent, robust, and trusted data access remains crucial for enabling AI systems to support reliable and scalable hazard monitoring and adaptive crisis response [16]. AI and advanced ICT can help collect, process, analyze, and disseminate vast and heterogeneous data streams [4]. Machine learning algorithms and natural language processing now allow for standardization and normalization of diverse inputs, extraction of risk factors from unstructured data, and integration of social, physical, and health-related signals to support better-informed decisions [17], [18]. However, the absence of unified or standardized data access approaches can hinder interoperability, slow critical updates, and introduce errors in high-stakes applications [19].

Addressing the urgent need for reliable, standardized, and open-access environmental data systems is foundational for the next generation of AI-enabled early warning and crisis management platforms [20]. The introduction of Model-Context-Protocol (MCP) has paved the way for standardizing the access to different tools and datasets for AI agents [21], [22]. This article introduces WeatherInfo\_MCP, our development of a specialized MCP to help AI agents across diverse environmental applications access the information they need. The initial motivation behind developing WeatherInfo\_MCP was to support an agentic AI system for managing heatwave scenarios, highlighting the protocol's value in separating data extraction from the broader agentic workflow. This separation acts as a common data access layer, fostering correctness, security, and allowing agent developers to focus on core logic rather than duplicative data integration work. This architecture facilitates the shift from the

traditional  $M \times N$  integration problem, where  $M$  agents need to interface with  $N$  data sources, to a simpler  $M + N$  solution, where the MCP acts as the intermediary (Figure 1).



**Figure 1.** Using WeatherInfo\_MCP reduces the complexity of data access to a multi-agent system. (a) Without WeatherInfo\_MCP, (b) with WeatherInfo\_MCP; Access to the dashed and grayed data sources is not included in this initial version.

The prospects for such integration promise not only better preparedness and reduced losses but also more equitable access to lifesaving information worldwide. We will continue with a brief explanation of MCP, then describe the futuristic design of WeatherInfo\_MCP v1.00, which applies software architecture standards to make future system expansion easier and straightforward.

## 2. Materials and Methods

### 2.1. Model-Context-Protocol (MCP)

The Model Context Protocol (MCP) is an open standard that was recently developed. It enables AI agents to securely and efficiently use digital tools and datasets [21]. MCP was formally introduced in November 2024, motivated by the rapid expansion of AI agents in different domains [22]. This shift highlights a critical, shared need for reliable methods for AI systems to access, query, and manipulate up-to-date, real-world information. Without MCP, most autonomous AI agents require custom code or proprietary interfaces to connect with new data sources or software platforms [23]. This can lead to increased development overhead, frequent errors, and significant systemic security risks, particularly concerning data privacy and authorization. MCP addresses these challenges by providing a unified, transparent, and extensible technical solution [24]. By providing a standard interface, the hard-coding of data access can be separated from the development of agents so developers can more easily build robust AI agents that interact correctly with complex information systems—such as climate databases, sensor networks, or data analytics tools—without risking interoperability breakdowns across different platforms.

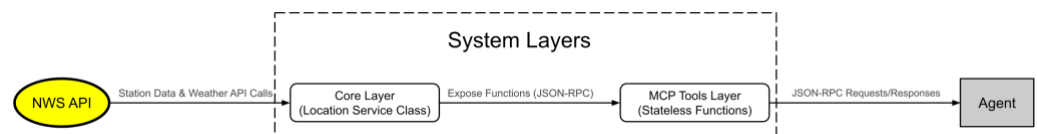
At its core, MCP structures communications as a series of standardized “tool calls” or function requests [22]. This process allows an agent to request specific operations, fetch data, or trigger actions in external systems using simple, well-defined formats, typically relying on secure, lightweight HTTPS exchanges. MCP servers expose modular capabilities, where each “tool” corresponds to a distinct unit of function—such as retrieving weather data, querying a document archive, or performing a specific risk calculation. This design separates the AI model’s probabilistic reasoning core from the deterministic external data access layer, greatly enhancing system security and observability.

MCP is expected to play a major role in the future of AI deployment for different purposes, including sustainable development and crisis management. Its modular

architecture and open ecosystem enable organizations to rapidly innovate and scale AI solutions, ensuring the robustness and reproducibility required for high-stakes applications such as climate risk assessment and autonomous decision support. This standardized approach to grounding LLM-powered agents is essential for transforming siloed AI efforts into resilient, trustworthy, and interoperable agent networks. In the following sections, we introduce our MCP server, WeatherInfo\_MCP.

## 2.2. WeatherInfo\_MCP

The design of WeatherInfo\_MCP emphasizes modularity, efficiency, and standards-based communication to support robust, maintainable, and extensible service delivery. The package was designed in two focused parts that are explained in the following. The first part includes a service-oriented core architecture and an object-oriented design of the geospatial data model. The second part is a Model Context Protocol (MCP) layer that exposes the functionality of WeatherInfo\_MCP to AI agents through a standardized, stateless interface. Figure 2 shows the system with the separation of these layers.



**Figure 2.** WeatherInfo\_MCP system architecture depicting its two-part design. Data flows from the NWS API to AI agents via stateless, serialized endpoints.

### 2.2.1. Service-Oriented Core Architecture and the Object Model

For the WeatherInfo\_MCP design, we opted for a Service-Oriented Architecture (SOA) [25]. This approach lets us break the system into independent services that talk to each other through standard interfaces. By decoupling these components, we gained the ability to scale or update specific parts of the software without overhauling the entire codebase. At the core of WeatherInfo\_MCP’s architecture is a service class named “Location”, which follows recommended best practices by encapsulating all data access and geospatial operations. Upon instantiation, a Location object either accepts an address or direct coordinates. If an address is provided, it is geocoded into latitude and longitude through a controlled process with retry and timeout controls to handle network unreliability.

Immediately after creation, the Location object resolves and caches the URL of the nearest National Weather Service (NWS) observation station. This URL serves as a unique, persistent identity attribute of the location. Caching this station link minimizes repeated API calls during subsequent weather data retrievals, thereby reducing unnecessary network traffic. Variable data, such as temperature, humidity, and wind, are accessed on demand through methods of the class, distinguishing between relatively constant properties (location and station identities) and dynamically changing observations.

To enable long-lived or distributed use, the Location object supports serialization—conversion to a JSON-compatible dictionary—which can be safely stored, transmitted, and later reconstructed into a live object. This serialization is necessary since the Model Context Protocol operates over JSON-RPC, which requires exchanging JSON-serializable data structures rather than raw Python objects [26].

This design pattern ensures that each MCP tool call restores a fully functional Location instance from its serialized form. This approach enforces isolation between calls, prevents state sharing-related bugs, and allows session persistence or multi-agent communication where the same location information is reused efficiently.

### 2.2.2. MCP Layer: Agent Interaction and Protocol Design

WeatherInfo\_MCP server uses the Model Context Protocol (MCP) to expose its core functionality to AI agents through stateless functions that are decorated to handle specific agent requests [27]. Each function operates independently to process location data and retrieve specific weather metrics. These functions provide structured outputs with clear documentation to ensure accurate identification and utilization of the server's capabilities by agents.

This modular design follows established best practices for building reliable and scalable AI systems by providing independently operating tools that rely on a shared central processing unit. By isolating each function, the system ensures that complex requests can be handled concurrently without interference, maximizing stability for decision-making applications. The separation of the MCP layer from the Location service class simplifies maintenance and extension since new weather variables or extraction functions can be added by writing additional stateless MCP tools without altering the core data access code.

To minimize network load, the system consolidates data retrieval into a single step, occurring only when a new location is defined or when a live update is explicitly requested. All subsequent analysis is performed on this locally stored dataset rather than repeatedly querying the external source, aligning with established efficiency standards [28]. This enhanced design, grounded in recognized architectural standards such as SOA and MCP, results in a flexible, maintainable, and efficient system. It is well suited for integrated, AI-driven environmental monitoring and other related applications that require access to meteorological data.

## 3. Results

To ensure the reliability of the WeatherInfo\_MCP tool, we conducted extensive unit tests and comprehensive MCP tests, following best practices in modern software engineering and the MCP requirements. Unit tests verified the accuracy of each core component (such as location geocoding and weather data processing). In contrast, broader test cases of the MCP layer assessed the tool's robustness in various real-world scenarios, as explained in more detail in the following sections. Additionally, we simulated a simple agentic model integrating WeatherInfo\_MCP with a memory MCP. All critical tests were run using industry-standard testing frameworks, and the results are summarized in the following sections. This approach assures end users and stakeholders of the tool's trustworthiness. The GitHub repo with open-source code is available at this link: [https://github.com/Babakifard/weatherinfo\\_mcp](https://github.com/Babakifard/weatherinfo_mcp).

### 3.1. Unit Tests

Unit testing is a foundational practice in software development where individual components of a program are tested separately to ensure they behave correctly [29]. By testing each part in isolation, developers can quickly identify and fix errors, which leads to higher software quality and easier maintenance to ensure reliability, reproducibility, and credibility. We implemented unit tests for all functions in the two central Python modules of WeatherInfo\_MCP. These tests cover crucial capabilities, such as initializing Location objects from addresses or coordinates, retrieving weather observation data, and extracting specific weather parameters, including temperature, humidity, and wind. To make the tests efficient and reliable, we used a technique called mocking [30]. Mocking simulates external systems or network calls, allowing tests to run without making real

requests to service APIs. This ensures the tests are fast, reproducible, and unaffected by network issues or external service availability.

The test suite was written using Python’s unittest framework supplemented by mocks for network interactions. It includes 14 distinct test cases spanning both core location services and weather tool MCP components, that validates both success and error handling scenarios comprehensively. All tests passed successfully, underlining the reliability of WeatherInfo\_MCP’s fundamental functions. These unit tests provide confidence that each component performs as designed, serving as a robust foundation for building advanced agentic systems that use WeatherInfo\_MCP. Such agentic systems can use WeatherInfo\_MCP to attain dependable weather information by means of conversation rather than embedded coding or expertise in accessing related APIs. This is shown through a simple example later in this manuscript.

### 3.2. Rigorous Validation of MCP Tool Compliance

To ensure that the WeatherInfo\_MCP tool meets the standards of reliability, interoperability, and robustness expected for modern agentic systems, we conducted a comprehensive test suite in line with the Model Context Protocol (MCP) 2025-06-18 specification and related best practices [24]. Each category of test addresses a specific aspect of system behavior that is critical for correct, predictable functioning in real-world, multi-agent, and multi-MCPs environments. Below are the seven test categories over four areas—each completed and passed for WeatherInfo\_MCP—along with a brief explanation of their purpose and connection to current standards:

1. MCP Protocol Compliance (2025-06-18):
  - a. Tool Manifest Validation: Validates the presence and correctness of the entire tool manifest. This guarantees the discoverability of the functions for agents.
  - b. Tool Execution Validation: Confirms the correct execution of declared tools, such as `create_location` and related utilities, and delivery of expected outputs for valid input.
2. Session and Lifecycle Management
  - a. Protocol Version Negotiation: Ensures accurate communication of the MCP protocol version.
  - b. Session Initialization and State Management: Assesses robust session creation, state transitions, maintenance, and cleanup, ensuring stable and predictable operation, especially in continuous or long-running deployments.
3. Error Handling & Recovery
  - a. Investigates system responses to invalid inputs, malformed requests, and external API timeouts. The test verified that the system fails gracefully under stress conditions (such as rapid sequential requests or upstream API outages), preserving data integrity. Multi-user load testing was not conducted because the system is designed to run as an independent instance for each user. This design inherently prevents one user's heavy usage from slowing down or affecting another's session.
4. WeatherInfo\_MCP-Specific Functional Tests
  - a. Focuses on domain-relevant capabilities unique to WeatherInfo\_MCP, including location-aware weather queries, observation retrieval, and alert

serving, ensuring correct operation and robustness for real-world environmental health use cases.

Security Compliance was not tested in this deployment, as WeatherInfo\_MCP handles only public, non-sensitive information and does not introduce risks related to privacy, authorization, or data protection per MCP security requirements. This category will be revisited if future versions require the handling of sensitive data. Table 1 summarizes the test results and coverage for WeatherInfo\_MCP. In total, the testing program comprised 23 unique tests, with every category achieving a 100% pass rate. These results provide comprehensive evidence that WeatherInfo\_MCP conforms to core MCP 2025-06-18 standards and is robust for deployment in agentic environments.

**Table 1.** Summary of WeatherInfo\_MCP Testing Coverage and Outcomes in Accordance with MCP 2025-06-18 Standards.

No.	Category	Test Name	Total Tests	% Passed	Notes
1	MCP Protocol Compliance 2025-06-18	Tool Manifest, Connection, and Execution Validation	3	100%	Validated initialization, tool manifest (8 tools), and execution of create_location
			7	100%	Includes protocol version negotiation and lifecycle tests, including session initialization and session state transition
2	Session and Lifecycle Management	Protocol Version Negotiation			
3	Error Handling & Recovery	Error Handling & Recovery	10	100%	Comprehensive error, retry, and timeout handling tests
			3	100%	Location creation, weather observation, and alert retrieval
4	MCP-Specific Functional Tests	MCP-Specific Functional Tests			
5	Security Compliance	Security Compliance	0	100%	Not tested; system does not handle sensitive information

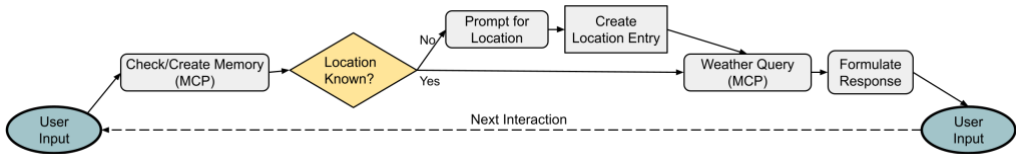
### 3.3. A Simple Use-Case: An AI-agent using WeatherInfo\_MCP and a memory MCP

To demonstrate the practical applicability and integration capability of the WeatherInfo\_MCP tool within an agent-based system, a working AI agent was developed that incorporates two MCP servers: WeatherMCP and a memory MCP. This configuration enables the agent to provide real-time meteorological data while managing persistent user-related information, such as locations linked to individual names. The setup was



designed to test the agent’s ability to maintain personalized context and operate the two MCP instances seamlessly within a single framework. We used OpenAI’s Agent SDK framework with gpt-4o-mini as the backend LLM for our test case, but WeatherInfo\_MCP can be used by any agent frameworks and LLM [31].

The agent’s instructions guide it to identify the individual upon interaction and check for stored entities representing this person and their associated locations. If a location is not already stored, the agent prompts the individual to provide this information and subsequently saves it using the memory MCP. This strategy ensures that after the initial identification, the location data is persistently linked to the individual, allowing the agent to avoid redundant location queries in subsequent sessions, or interactions. Weather information retrieval is then conducted by querying the WeatherInfo\_MCP server for up-to-date observations, such as temperature, humidity, wind conditions, and descriptive weather summaries. Figure 3 illustrates this agent workflow.



**Figure 3.** Workflow diagram of a single agent session in our sample case.

An example of a session with three interactions illustrates the agent’s capabilities (Table 2). In the first interaction scenario, we introduced John Dove and specified his location as Omaha, Nebraska. The agent successfully creates entities for John and Omaha, establishes their relationship, and fetches the current weather observations for Omaha from the WeatherInfo\_MCP tool. The agent responds with a detailed yet clear summary including temperature, wind speed, and direction, and relative humidity. In a subsequent interaction (Interaction 3 in Table 2), the same person - John Dove- inquiries about weather alerts. The agent then retrieves corresponding entities for John and Omaha, establishes their relationship, and fetches active alerts associated with Omaha and reports their status appropriately. Also, using a new name without a related location - Bobby Jones in interaction 2 of Table 2- receives a message by the agent to provide their location.

These demonstrations shows a sample of how WeatherInfo\_MCP can be effectively embedded as a component in larger multi-tool AI agent architectures, facilitating dynamic, context-aware user interactions. The agent’s ability to coordinate between persistent memory and live data retrieval highlights the tool’s readiness for real-world applications, complementing the previously described unit and protocol compliance tests with evidence of operational robustness in interactive settings.bDetailed agent instruction prompts, and relevant code snippet are provided in the Appendix A to ensure transparency and reproducibility.

**Table 2.** The outcome generated by the sample agent system using WeatherInfo\_MCP alongside a memory MCP. The list includes interactions with a single agent in a single session, testing with different combinations of names and locations.

Interaction	Speaker	Utterance
1	User	Hi. My name is John Dove and I live in Omaha, Nebraska. What's the weather like today?
	Agent	John, the current weather in Omaha, Nebraska is clear with a temperature of about 9°C (48°F). The wind is coming from the north-northwest at approximately 24 km/h (15 mph) with

		gusts up to 33 km/h (21 mph). The relative humidity is around 57%.
2	User	Hi. I am Bobby Jones. Is there any weather alert today?
	Agent	I don't have your location saved yet. Could you please tell me the city or area where you are located? This will help me check for any weather alerts for your location.
3	User	Hi. I am John Dove. Is there any weather alert today?
	Agent	Hello John Dove. There are no weather alerts for Omaha, Nebraska today.

4. Discussion

We explained WeatherInfo\_MCP, a Model-Context-Protocol implementation built on the National Weather Service (NWS) API to standardize weather data access for AI agents. Our design employs a utility-server pattern and Service-Oriented Architecture (SOA), which strictly separates the core meteorological model logic from the MCP interface layer. This modular approach is a key strength, enhancing maintainability, flexibility, and extensibility, allowing for future integrations (e.g., memory MCPs) with minimal disruption. Crucially, WeatherInfo\_MCP conforms rigorously to the latest MCP standard specification (July 2025), confirmed through extensive testing, ensuring seamless interoperability within multi-MCP agent environments.

Several MCP weather servers have been developed and publicly released in the past year, providing weather data access through well-known APIs such as OpenWeatherMap, Open-Meteo, or the National Weather Service (Table A.3 in Appendix A). These servers vary in scope from simple API wrappers offering limited forecast and alert querying to more complex implementations with modular designs and integration examples. Our MCP weather server distinguishes itself through two major strengths that address key challenges for developers and AI researchers working with agentic frameworks. First, it uses SOA architecture to separate the core meteorological model functionalities from the MCP interface and control logic. Second, our MCP server conforms rigorously to the latest MCP standard specification (2025-06-18 version). To our knowledge, many existing MCP weather servers have not yet undergone such detailed conformance testing, making this a key differentiator for robust and scalable use of WeatherInfo\_MCP in AI assistant research and applications. It is important to clarify that our statements reflect the information available from public repositories and documentation of other MCP servers; we have not conducted exhaustive performance or feature testing across all products. Therefore, while we highlight these distinctive aspects of our MCP server, we welcome future benchmarking studies to establish broader performance and capability comparisons within the community. Section A.3 in Appendix A presents an overview to these MCPs with links for further exploration.

The current implementation relies on the NWS API, which restricts geographic coverage to the United States and presents limitations in spatial and temporal resolution, as data is often sourced from the nearest airport or major weather station. Therefore, the initial version (v0.1.0) is not optimized for localized data extraction at the neighborhood level. To overcome this, future development will integrate supplementary, local data sources—such as Purple Air sensors—alongside advanced geocoding services to improve spatial resolution. Furthermore, the long-term success of this tool relies on continuous adaptation to evolving standards. Also, as with any data-centric system, the utility of this tool is directly constrained by the quality, availability, and consistency of the upstream data providers.

## 5. Conclusions

WeatherInfo\_MCP v0.1.0 represents a crucial step toward democratizing reliable and flexible environmental data access for AI-driven applications. Designing robust data access protocols using open standards accelerates transformative advances across disciplines, including public health, emergency management, agriculture, and environmental monitoring. By providing a universal connectivity layer, this system relieves researchers and system designers of the complex burden of raw data integration. This enables AI agents to deliver highly targeted, individual-level warnings informed by specific location and health data, while allowing institutional platforms to efficiently process large-scale datasets for coordinated planning. The broader vision is that the adoption of AI-driven decision support, rooted in standardized protocols, will democratize complex analytic capabilities and improve preparedness, ultimately empowering individuals and communities to take informed action against accelerating environmental risks.

**Supplementary Materials:** Appendix A and Appendix B.

**Author Contributions:** Conceptualization, Babak J. Fard, Sadid A. Hasan and Jesse E. Bell; Data curation, Babak J. Fard; Formal analysis, Babak J. Fard; Investigation, Babak J. Fard; Methodology, Babak J. Fard and Sadid A. Hasan; Software, Babak J. Fard; Validation, Babak J. Fard; Writing—original draft, Babak J. Fard; Supervision, Sadid A. Hasan; Writing—review and editing, Sadid A. Hasan and Jesse E. Bell; Funding acquisition, Jesse E. Bell.

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**Data Availability Statement:** The repository of the described system can be found at the following address: [https://github.com/Babakjard/weatherinfo\\_mcp](https://github.com/Babakjard/weatherinfo_mcp)

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**Conflicts of Interest:** The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

## Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
LLMs	Large Language Models
MCP	Model-Context-Protocol
NWS	National Weather Service
SOA	Service Oriented Architecture
WMO	World Meteorological Organization

## Appendix A

### Appendix A.1. Agent Instruction Prompt

```

"""
You are a weather assistant with two specialized MCP tools:
1. A weather data tool for live weather information.
2. A memory management tool for storing and recalling user-
related information.

Your responsibilities:
- Provide accurate and context-aware weather information.
- Maintain persistent memory of users and their associated
locations.

Capabilities:
- Retrieve weather observations (temperature, humidity, wind,
weather description).
- Report weather alerts only when the user explicitly asks for
them.
- Provide relevant heat risk context as appropriate.
- Create, recall, and update user and location entities in long-
term memory.

Memory and Identification Workflow:
Always begin by identifying the user. Use memory to check for
an existing entity representing this person.
Use consistent entity naming when saving people, e.g.:
    person_<user_name> → location_<city_name>
If a person or location entity does not exist, create both:
    - person entity: represents the user (e.g. "John Doe")
    - location entity: represents their location (e.g. "New
York, NY")
    - create_relation: link person to location using "lives_in"
After identifying the entities, use the stored location for all
weather queries.

Weather Query Workflow:
Retrieve user's stored location (if exists).
If not found, ask for it, then store using the memory tool.
Fetch new weather data using get_current_observation.
Extract only the requested details (e.g. temperature, humidity,
or heat risk).
Only check and report active weather alerts if the user
explicitly mentions alerts or warnings.

Response Guidelines:
Never ask for a location again if it is already stored in
memory.
Persist all newly discovered user details consistently.
Recognize returning users by their saved memory entities.
Only mention weather alerts when explicitly requested.

```

Always prioritize clarity, factual accuracy, and contextual completeness in responses.

"""

## *Appendix A.2. Python code snippet to create the sample agent*

```
# MCP server params
params_weather_mcp = {"name": "heat-mcp",
                      "command": "python",
                      "args": ["-m",
                              "heat_mcp.mcp_tools.main"],
                      "env": {"PYTHONPATH":
                              "/path/to/heat_mcp/src"}}
params_memory_mcp = {"name": "memory-", "command": "npx",
                    "args": ["-y", "mcp-memory-libsql"],
                    "env": {"LIBSQL_URL":
                              "file:./memory/test_memory.db"}}

# Create and connect MCP servers
weather_server = MCPServerStdio(params=params_weather_mcp,
                                client_session_timeout_seconds=30)
memory_server = MCPServerStdio(params=params_memory_mcp,
                                client_session_timeout_seconds=30)
mcp_servers = [weather_server, memory_server]

# Create agent
agent = Agent(
    name="weather-agent",
    instructions=instructions,
    model="gpt-4.1-mini",
    mcp_servers=mcp_servers
)

# Running example query
question = "Hi. My name is John Dove and I live in Omaha,
Nebraska. What's the weather like today?"
for server in mcp_servers:
    await server.connect()
result = await Runner.run(agent, question, max_turns=10)
print(result.final_output)
```

## **Appendix B**

### *Appendix B.1. Unit Test Report*

```

===== test session starts =====
platform darwin -- Python 3.12.11, pytest-8.4.2, pluggy-1.6.0 -- /Users/babak.jfard/projects/HeatMCP/heat_mcp/.venv/bin/python
cachedir: .pytest_cache
rootdir: /Users/babak.jfard/projects/HeatMCP/heat_mcp
configfile: pyproject.toml
plugins: anyio-4.10.0
collected 14 items

tests/test_nws_location_service.py::TestLocationCore::test_get_current_observation_error PASSED [ 7%]
tests/test_nws_location_service.py::TestLocationCore::test_get_current_observation_success PASSED [ 14%]
tests/test_nws_location_service.py::TestLocationCore::test_init_missing_params_works PASSED [ 21%]
tests/test_nws_location_service.py::TestLocationCore::test_init_with_address PASSED [ 28%]
tests/test_nws_location_service.py::TestLocationCore::test_init_with_latlon PASSED [ 35%]
tests/test_nws_location_service.py::TestLocationCore::test_init_with_latlon_stores_values PASSED [ 42%]
tests/test_nws_weather_tools.py::TestWeatherToolsUpdated::test_create_location PASSED [ 50%]
tests/test_nws_weather_tools.py::TestWeatherToolsUpdated::test_extraction_with_missing_data PASSED [ 57%]
tests/test_nws_weather_tools.py::TestWeatherToolsUpdated::test_get_alerts PASSED [ 64%]
tests/test_nws_weather_tools.py::TestWeatherToolsUpdated::test_get_current_observation PASSED [ 71%]
tests/test_nws_weather_tools.py::TestWeatherToolsUpdated::test_get_humidity_from_observation PASSED [ 78%]
tests/test_nws_weather_tools.py::TestWeatherToolsUpdated::test_get_temperature_from_observation PASSED [ 85%]
tests/test_nws_weather_tools.py::TestWeatherToolsUpdated::test_get_weather_description_from_observation PASSED [ 92%]
tests/test_nws_weather_tools.py::TestWeatherToolsUpdated::test_get_wind_info_from_observation PASSED [100%]

===== 14 passed in 1.21s =====

```

## Appendix B.2. Comprehensive stdio MCP conformance test report

=====

### ☑ Testing stdio-based MCP server with comprehensive validation

Server Command: /Users/babak.jfard/projects/WeatherInfoMCP/weatherinfo\_mcp/.venv/bin/python

Server Args: ['-m', 'weatherinfo\_mcp.mcp\_tools.main']

Server CWD: /Users/babak.jfard/projects/WeatherInfoMCP/weatherinfo\_mcp

Protocol Version: 2025-06-18

Test Date: 2025-12-10 15:55:36

#### Summary:

-----

Total Tests: 7

Passed: 7

Failed: 0

Success Rate: 100.0%

#### Test Categories:

-----

Base MCP Protocol: 3 tests (3 passed)

WeatherInfo\_MCP Specific: 3 tests (3 passed)

MCP Inspector: 1 tests (1 passed)

#### Detailed Results:

-----

#### ✓ PASS: [BASE] Base MCP Connection and Initialization (0.19s)

MCP Spec: Base Protocol - Lifecycle

Details: {

"protocol\_version": "2025-06-18",

"has\_capabilities": true,

"has\_server\_info": true,

"server\_name": "nws\_weather\_server",

"server\_version": "1.13.0"

}

#### ✓ PASS: [BASE] Base MCP Tool Manifest Compliance (0.19s)

MCP Spec: Server Features - Tools

Details: {

"tools\_found": 8,

```

    "all_tools_valid": true
  }
✓ PASS: [BASE] Base MCP Tool Execution Compliance (3.72s)
  MCP Spec: Server Features - Tools
  Details: {
    "tool_executed": "create_location",
    "has_result": true,
    "result_type": "CallToolResult"
  }
✓ PASS: [WEATHERINFO_MCP] WeatherInfo_MCP Tool Availability (0.22s)
  MCP Spec: Server Features - Tools
  Details: {
    "expected_tools": [
      "create_location",
      "get_current_observation",
      "get_temperature_from_observation",
      "get_humidity_from_observation",
      "get_weather_description_from_observation",
      "get_wind_info_from_observation",
      "get_alerts",
      "get_HeatRisk"
    ],
    "available_tools": [
      "create_location",
      "get_current_observation",
      "get_temperature_from_observation",
      "get_humidity_from_observation",
      "get_weather_description_from_observation",
      "get_wind_info_from_observation",
      "get_alerts",
      "get_HeatRisk"
    ],
    "missing_tools": [],
    "all_tools_present": true
  }
✓ PASS: [WEATHERINFO_MCP] WeatherInfo_MCP Location Creation (1.35s)
  MCP Spec: Server Features - Tools
  Details: {
    "location_created": true,
    "address": "San Francisco, CA",
    "latitude": 37.7879363,
    "longitude": -122.4075201,
    "has_station_url": true
  }
✓ PASS: [WEATHERINFO_MCP] WeatherInfo_MCP Weather Observation (3.01s)
  MCP Spec: Server Features - Tools
  Details: {
    "observation_retrieved": true,
    "has_timestamp": true,
    "has_temperature": true,
    "has_humidity": true,

```

```
"observation_keys": [  
    "@id",  
    "@type",  
    "elevation",  
    "station",  
    "stationId",  
    "stationName",  
    "timestamp",  
    "rawMessage",  
    "textDescription",  
    "icon"  
]  
}  
✓ PASS: [INSPECTOR] MCP Inspector Availability (0.53s)  
  MCP Spec: Developer Tools  
  Details: {  
    "inspector_available": true,  
    "npx_accessible": true,  
    "help_output_length": 559  
  }  
}
```

#### Test Coverage:

- ✓ Base MCP Protocol Tests:
  - Connection and Initialization (Base Protocol - Lifecycle)
  - Tool Manifest Compliance (Server Features - Tools)
  - Tool Execution Compliance (Server Features - Tools)
- ✓ WeatherInfo\_MCP-Specific Tests:
  - Tool Availability Validation
  - Location Creation Functionality
  - Weather Observation Retrieval
- ✓ MCP Inspector Integration:
  - Inspector Tool Availability
  - CLI Integration Testing

#### Compliance Status:

- ✓ COMPREHENSIVE TESTING with MCP specification version 2025-06-18
- ✓ All required protocol components tested
- ✓ Proper stdio transport implementation
- ✓ FastMCP server compatibility validated
- ✓ WeatherInfo\_MCP-specific functionality validated

#### References:

- MCP Specification: <https://modelcontextprotocol.io/specification/2025-06-18>
- FastMCP Documentation: <https://github.com/modelcontextprotocol/python-sdk>
- MCP Inspector: <https://modelcontextprotocol.io/docs/tools/inspector>
- WeatherInfo\_MCP Documentation: [../README.md](#)



All appendix sections must be cited in the main text. In the appendices, Figures, Tables, etc. should be labeled starting with "A"—e.g., Figure A1, Figure A2, etc.

## References

1. World Meteorological Organization, "Weather-related disasters increase over past 50 years, causing more damage but fewer deaths." Aug. 2021. [Online]. Available: <https://wmo.int/media/news/weather-related-disasters-increase-over-past-50-years-causing-more-damage-fewer-deaths>
2. Climate Central, "U.S. Sees 14 Billion-Dollar Disasters in First Half of 2025." July 2025. [Online]. Available: <https://www.climatecentral.org/climate-matters/billion-dollar-disasters-2025>
3. "U.S. Billion-Dollar Weather and Climate Disasters | Climate Central." Accessed: Jan. 05, 2026. [Online]. Available: <https://www.climatecentral.org/climate-services/billion-dollar-disasters>
4. "Chapter 1 AI-based Approach in Early Warning Systems: Focus on Emergency Communication Ecosystem and Citizen Participation in Nordic Countries." Accessed: Nov. 12, 2025. [Online]. Available: <https://arxiv.org/html/2506.18926v1>
5. "Forecasting and management of disasters triggered by climate change," in *Visualization Techniques for Climate Change with Machine Learning and Artificial Intelligence*, Elsevier, 2023, pp. 181–207. doi: 10.1016/B978-0-323-99714-0.00019-4.
6. World Meteorological Organization, "Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019)." 2021. [Online]. Available: [https://library.wmo.int/index.php?lvl=notice\\_display&id=21930](https://library.wmo.int/index.php?lvl=notice_display&id=21930)
7. H. Johar et al., "Community-based heat adaptation interventions for improving heat literacy, behaviours, and health outcomes: a systematic review," *Lancet Planet. Health*, vol. 9, no. 7, July 2025, doi: 10.1016/S2542-5196(25)00007-5.
8. N. A. Errett and others, "Survey of extreme heat public health preparedness plans and response activities in the most populous jurisdictions in the United States," *BMC Public Health*, vol. 23, no. 1, p. 811, May 2023, doi: 10.1186/s12889-023-15757-x.
9. C. G. Hoehne et al., "Heat exposure during outdoor activities in the US varies significantly by city, demography, and activity," *Health Place*, vol. 54, pp. 1–10, Nov. 2018, doi: 10.1016/j.healthplace.2018.08.014.
10. S. K. Mukkavilli and others, "AI Foundation Models for Weather and Climate Applications, Design, and Implementation." 2023. [Online]. Available: <https://arxiv.org/abs/2309.10808>
11. L. Chen and others, "Machine Learning Methods in Weather and Climate Applications: A Survey," *Appl. Sci.*, vol. 13, no. 21, p. 12019, 2023, doi: 10.3390/app132112019.
12. E. Törnquist and others, "Balancing Computational Efficiency and Forecast Error in Machine Learning-based Time-Series Forecasting: Insights from Live Experiments on Meteorological Nowcasting." 2023. [Online]. Available: <https://arxiv.org/abs/2309.15207>
13. B. Kim and T. Kim, "AI in extreme weather events prediction and response: a systematic topic-model review (2015–2024)," *Front. Environ. Sci.*, vol. 13, Sept. 2025, doi: 10.3389/fenvs.2025.1659344.
14. World Meteorological Organization, "Forecasting the Future: The Role of Artificial Intelligence in Transforming Weather Prediction and Policy." 2025. [Online]. Available: <https://wmo.int/media/magazine-article/forecasting-future-role-of-artificial-intelligence-transforming-weather-prediction-and-policy>
15. F. Wetterhall, A. Zollo, and S. Colombelli, "A roadmap to Multi-Risk Impact-Based Early Warning System for Weather and Geo Hazards in Europe." 2025. doi: 10.5194/ems2025-689.
16. V. Q. A. Cao and others, "Current status and challenges in operating flood early warning systems at the local level in Japan," *International Journal of Disaster Risk Reduction* 112, 2024: 104802.
17. S. Akter and S. F. Wamba, "Big data and disaster management: a systematic review and agenda for future research," *Ann. Oper. Res.*, vol. 283, no. 1, pp. 939–959, Dec. 2019, doi: 10.1007/s10479-017-2584-2.
18. M. Imran, C. Castillo, F. Diaz, and S. Vieweg, "Processing Social Media Messages in Mass Emergency: A Survey," *ACM Comput Surv*, vol. 47, no. 4, p. 67:1–67:38, June 2015, doi: 10.1145/2771588.
19. Giambelli M, Meninno S, Deda M, Paniccia C, Vio R, Renzulli S, Morando M, Ponte E, Massabò M., "Linking early warnings to early actions through system approach: learnings from pilots in Western Balkans and Türkiye." 2023. doi: 10.5194/egusphere-egu23-14368.
20. S. A. Vaghefi and others, "AI for Climate Finance: Agentic Retrieval and Multi-Step Reasoning for Early Warning System Investments." 2025. doi: 10.48550/arxiv.2504.05104.
21. Anthropic, "Introducing the Model Context Protocol," Announcements. [Online]. Available: <https://www.anthropic.com/news/model-context-protocol>

22. A. Ehtesham, A. Singh, G. K. Gupta, and S. Kumar, "A survey of agent interoperability protocols: Model Context Protocol (MCP), Agent Communication Protocol (ACP), Agent-to-Agent Protocol (A2A), and Agent Network Protocol (ANP)," May 23, 2025, arXiv: arXiv:2505.02279. doi: 10.48550/arXiv.2505.02279.
23. A. S. Shethiya, "LLM-Powered Architectures: Designing the Next Generation of Intelligent Software Systems," Acad. Nexus J., vol. 2, no. 1, 2023, Accessed: Nov. 21, 2025. [Online]. Available: <http://academianexusjournal.com/index.php/anj/article/view/21>
24. P. P. Ray, "A Survey on Model Context Protocol: Architecture, State-of-the-art, Challenges and Future Directions", Accessed: Nov. 12, 2025. [Online]. Available: <https://www.authorea.com/users/913189/articles/1286748-a-survey-on-model-context-protocol-architecture-state-of-the-art-challenges-and-future-directions>
25. E. A. Marks and M. Bell, Eds., Service-Oriented Architecture: A Planning and Implementation Guide for Business and Technology, 1st ed. Wiley, 2012. doi: 10.1002/9781119201700.
26. JSON-RPC Working Group, "JSON-RPC 2.0 Specification." 2013. [Online]. Available: <https://www.jsonrpc.org/specification>
27. X. Hou, Y. Zhao, S. Wang, and H. Wang, "Model Context Protocol (MCP): Landscape, Security Threats, and Future Research Directions," Oct. 07, 2025, arXiv: arXiv:2503.23278. doi: 10.48550/arXiv.2503.23278.
28. M. Fowler, Patterns of enterprise application architecture. Addison-Wesley, 2012. Accessed: Dec. 12, 2025. [Online]. Available: [https://books.google.com/books?hl=en&lr=&id=vqTfNFDzzdIC&oi=fnd&pg=PR7&dq=Fowler,+M.+\(2002\).+Patterns+of+Enterprise+Application+Architecture.+Addison-Wesley.&ots=oVFIEuNOqD&sig=bD7FoqlhhivSPxYIAZnR14z5B-k](https://books.google.com/books?hl=en&lr=&id=vqTfNFDzzdIC&oi=fnd&pg=PR7&dq=Fowler,+M.+(2002).+Patterns+of+Enterprise+Application+Architecture.+Addison-Wesley.&ots=oVFIEuNOqD&sig=bD7FoqlhhivSPxYIAZnR14z5B-k)
29. "IEEE Standard for Software Unit Testing," ANSIIEEE Std 1008-1987, 1987, doi: 10.1109/IEEESTD.1987.122713.
30. M. Fowler, "Mocks Aren't Stubs." [Online]. Available: <https://martinfowler.com/articles/mocksArentStubs.html>
31. X. Wang, S. Rosenberg, J. Michelini, C. Smith, and others, "The OpenHands Software Agent SDK: A Composable and Extensible Foundation for Production Agents," ArXiv Prepr. ArXiv251103690, 2025.