
Facilitating AI-Driven Sustainability: A Service-Oriented Architecture for Interoperable Environmental Data Access

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Peer Review Status: This paper is a non-peer reviewed preprint submitted to EarthArXiv. The manuscript is currently under review at the journal *Sustainability*.

Facilitating AI-Driven Sustainability: A Service-Oriented Architecture for Interoperable Environmental Data Access

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Abstract

Advances in Artificial Intelligence (AI), particularly agentic AI, have created opportunities to enhance global sustainability by improving the efficiency and accuracy of environmental monitoring and response systems. 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 for 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 support the sustainable development community, enabling broad adoption of AI agents for environmental use cases.

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

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 [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 resilience 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 work on 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 Information and Communications Technology (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]. By lowering the technical barriers to API integration, standardized protocols can facilitate broader access to environmental intelligence, potentially enabling non-expert developers to build robust decision-support tools. 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).

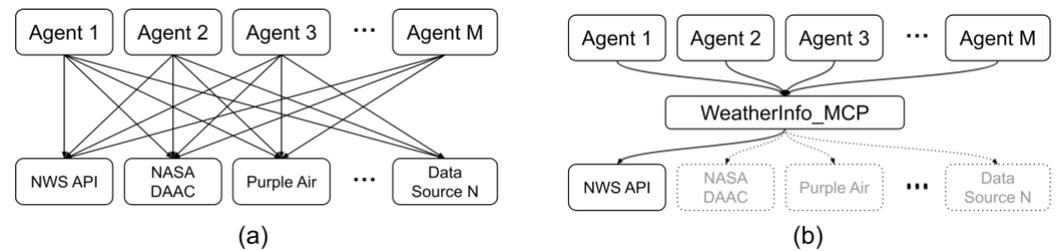


Figure 1. Using WeatherInfo_MCP reduces the complexity of data access to a multi-agent system. (a) Without WeatherInfo_MCP, (b) with WeatherInfo_MCP; Access to the dashed and grayed data sources is not included in this initial version.

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.

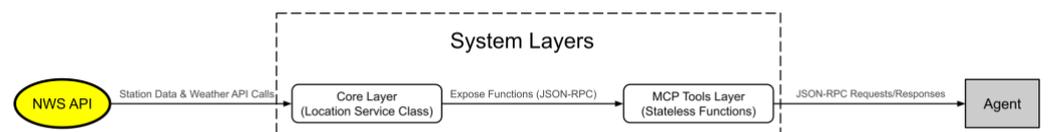


Figure 2. WeatherInfo_MCP system architecture depicting its two-part design. Data flows from the NWS API to AI agents via stateless, serialized endpoints.

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.

A key trade-off in this architecture is prioritizing separation of concerns over initial implementation speed. While a monolithic script would have reduced the codebase size, it would have created a dependency between the data extraction logic and the MCP interface. By isolating the Location server, we accepted a higher initial development effort to ensure that future changes to the NWS API do not propagate errors to the agent communication layer - a critical requirement for maintaining long-term autonomous systems. In addition, expanding the system to more data sources and capabilities in the future will be more straightforward in future versions.

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/Babakfard/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 WetherInfo_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 WeaeherInfo_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. The primary potential for misuse lies in operational resource consumption, where an autonomous agent might inadvertently generate excessive API requests. While the MCP architecture permits host-side throttling, the ultimate safeguard is enforced by the NWS upstream API rate limits, which automatically reject excessive traffic from a single IP address, preventing systemic disruption. 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

4	MCP-Specific Functional Tests	MCP-Specific Functional Tests	3	100%	Location creation, weather observation, and alert retrieval
5	Security Compliance	Security Compliance	0	100%	Not tested; system does not handle sensitive information

It is worth noting that the system operates as an I/O-bound application, where total response latency is dominated by the network Round-Trip Time (RTT) and processing time of the upstream NWS API. The internal overhead introduced by WeatherInfo_MCP's abstraction layer consists of in-memory serialization and logic execution, which is computationally negligible compared to the external HTTP request lifecycle [31]. Therefore, the modular architecture preserves the performance profile of direct API integration without introducing considerable latency.

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.

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.

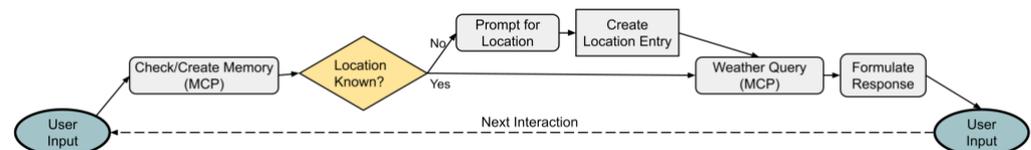


Figure 3. Workflow diagram of a single agent session in our sample case.

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- inquires 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. Detailed 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	<i>Hi. My name is John Dove and I live in Omaha, Nebraska. What's the weather like today?</i>
	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	<i>Hi. I am Bobby Jones. Is there any weather alert today?</i>
	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	<i>Hi. I am John Dove. Is there any weather alert today?</i>
	Agent	Hello John Dove. There are no weather alerts for Omaha, Nebraska today.

The presented agentic interaction is intentionally designed as a minimal validation scenario to isolate the reliability of the communication protocol from the variability of AI reasoning. In complex environmental modeling, higher order tasks - such as multi-variable inference or temporal reasoning- rely heavily on the capabilities of other models and tools such as the language model itself. Introducing such complexity at the validation stage would create confounding variables, making it difficult to distinguish between a failure in the tool's architecture and a failure in the agent's planning logic. By restricting the scope to a fundamental query-response cycle, this use case validates the determinism and stability of the underlying infrastructure, establishing a reliable foundation upon which more complex, reasoning-intensive applications can subsequently be built.

To facilitate independent verification of the system's interoperability, we have deployed a live reference implementation hosted on Hugging Face Spaces (accessible at: https://huggingface.co/spaces/Babak321/Simple_Weather_App). This web-based interface utilizes the WeatherInfo_MCP backend to power a conversational agent and alert notification system in a cloud environment. Note that this deployment is provided strictly as a functional proof-of-concept to demonstrate the stability of the standardized connection. The application-level design of the web app is illustrative and remains outside the scope of the architectural analysis presented in this study.

4. Discussion

Here 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.

To validate the operational benefits of WeatherInfo_MCP, we compared its integration workflow against a traditional direct API implementation. In a traditional setting, an AI agent developer must write custom code to handle HTTP requests, parse complex JSON responses from the NWS API, and manage connection errors. This creates a “tight coupling” - a high level of dependency between components of a software, where one module directly relies on the internal implementation details of another- between the agent and the data source, where any change in the NWS API requires updating the agent’s core code.

In contrast, WeatherInfo_MCP abstracts these complexities into a standardized interface. Table 3 presents a qualitative comparison of these two approaches across key software engineering metrics. Also, the provided sample jupyter notebook in the /notebooks/ folder of the provided GitHub shows a reimplementaion of the direct API use.

Table 3. 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.

Feature	Direct NWS AIP Integration	WeatherInfo_MCP (Proposed)
Integration Complexity	High: Requires handling HTTP headers, rate limits, and JSON parsing logic within the agent's codebase.	Low: Agent uses pre-defined tools (e.g., <code>get_weather</code>) without needing knowledge of the underlying API protocols.
Development Effort	Linear (M x N): Each new agent requires a fresh integration script for every new data source.	Modular (M + N): Once the MCP server is running, any number of agents can connect instantly without new code.
Error Handling	Manual: Developers must write custom logic to catch timeouts or 500-level errors for every request.	Built-in: The SOA core handles retries, timeouts, and graceful failures automatically before the agent sees a result.
Maintainability	Low: If the NWS API changes its endpoints, every agent's code must be rewritten.	High: API updates are handled once within the MCP server; agents remain unaffected.

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. All MCP servers listed in section A.3 are published before the latest MCP standard specification (2025-06-18 version), which makes them all susceptible to fail in such tests and consequently in real world applications. Among all the servers listed in section A.3 only Weather MCP (third in the table) and knmi-weather-mcp (last in the table) provide open-source code with separated utility and server functionalities, making them comparable to our SOA architecture benefits. However, that former is focused on data from Open-Meteo API, and the latter is only focused on the Netherlands. 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.

Despite the discussed strengths, the current implementation is subject to data constraints. This version 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 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 standardizing 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 [32], [33], [34]. By providing a universal connectivity layer, this system relieves researchers and system designers of the complex burden of raw data integration from the National Weather Service.

From a perspective of sustainable development, this work contributes to the creation of a resilient digital infrastructure capable of supporting integrated scientific approaches relying on agentic AI. By providing a standardized interface for environmental data access, the system directly facilitates the development and maintainability of AI agents designed for complex sustainability applications and research studies. This interoperability ensures reliable access of agents to the environmental context needed to address broader socio-economic challenges. Furthermore, by reducing the technical resources required to deploy environmental AI agents, this architecture fosters informational equity, enabling resource-constrained organizations and local governments to leverage advanced decision-making support tools for sustainability and environmental planning. This potentially enables AI agents to deliver highly targeted, individual-level weather data for a specific location, while allowing institutional platforms to efficiently process large-scale datasets for coordinated planning.

The broader vision is that establishing such technical infrastructures is a prerequisite for future AI-driven decision support systems. By decoupling data retrieval from agent reasoning, this architecture provides the necessary foundation for applications that improve preparedness and support individuals and communities to take informed action against accelerating environmental risks and sustainability challenges.

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.

Funding: This work was supported in part by the National Aeronautics and Space Administration (NASA) Research Opportunities in Space and Earth Sciences (ROSES) program (Grant no. 8ONSSC22K1050). Additional funding support was provided by the Claire M. Hubbard Foundation.

Data Availability Statement: The repository of the described system can be found at the following address: https://github.com/Babakjard/weatherinfo_mcp

Acknowledgments: During the preparation of this manuscript/study, the authors utilized Cursor and Perplexity AI to assist in refining the main code and designing the test scripts and validation protocols. Gemini and Perplexity AI were used to refine the manuscript text. SciSpace was used to ensure the validity and accuracy of citations for the latest related articles. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial interests or relationships that could be construed as a potential conflict of interest. The authors declare no conflicts of interest. The employers or 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.

```



```

        "args": ["-m", 572
"heat_mcp.mcp_tools.main"], 573
        "env": {"PYTHONPATH": 574
"/path/to/heat_mcp/src"}} 575
    params_memory_mcp = {"name": "memory-", "command": "npx", 576
        "args": ["-y", "mcp-memory-libsql"], 577
        "env": {"LIBSQL_URL": 578
"file:./memory/test_memory.db"}} 579
    580
    # Create and connect MCP servers 581
    weather_server = MCPServerStdio(params=params_weather_mcp, 582
client_session_timeout_seconds=30) 583
    memory_server = MCPServerStdio(params=params_memory_mcp, 584
client_session_timeout_seconds=30) 585
    mcp_servers = [weather_server, memory_server] 586
    587
    # Create agent 588
    agent = Agent( 589
        name="weather-agent", 590
        instructions=instructions, 591
        model="gpt-4.1-mini", 592
        mcp_servers=mcp_servers 593
    ) 594
    595
    # Running example query 596
    question = "Hi. My name is John Dove and I live in Omaha, 597
Nebraska. What's the weather like today?" 598
    for server in mcp_servers: 599
        await server.connect() 600
    result = await Runner.run(agent, question, max_turns=10) 601
    print(result.final_output) 602
    603
    604
    605

```

Appendix A.3. Links to other weather related MCP products.

MCP Name	MCP/Github Link	Initial Publication Date	Related Paper Link	Language
WeatherInfo_MCP (This model)	https://github.com/Babakifard/weather_info_mcp	2025	TBD	Python
OpenWeatherMap MCP	https://playbooks.com/mcp/rossshannon-openweathermap	2025-04-08	N/A	Python
Weather MCP (Jiri Spilka)	https://apify.com/jiri.spilka/weather-mcp-server https://github.com/isdaniel/mcp_weather_server	2025-05-29	N/A	Python
MCP-Weather (TimLukaHorstmann)	https://github.com/TimLukaHorstmann/mcp-weather	2025-05-03	N/A	TypeScript

MCP-Weather (adhikasp)	https://github.com/adhikasp/mcp-weather	2024-12-31	N/A	Unknown
MCP Weather Server (FlowHunt)	https://www.flowhunt.io/mcp-servers/mcp-weather/	2025-06-17	N/A	Unknown
OpenWeather MCP (RoystonDALmeida)	https://mcp.so/server/mcp-weather-server/RoystonDALmeida	Unknown	N/A	Unknown
knmi-weather-mcp	https://github.com/wolkwork/knmi-mcp	2025-02-27	N/A	Unknown

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Appendix B

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Appendix B.1. Unit Test Report

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```

===== 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 =====

```

610

611

Appendix B.2. Comprehensive stdio MCP conformance test report

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=====

613

☑ Testing stdio-based MCP server with comprehensive validation

615

Server Command: /Users/babak.jfard/projects/WeatherInfoMCP/weatherinfo_mcp/.venv/bin/python

616

Server Args: ['-m', 'weatherinfo_mcp.mcp_tools.main']

617

Server CWD: /Users/babak.jfard/projects/WeatherInfoMCP/weatherinfo_mcp

618

Protocol Version: 2025-06-18

619

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

620

621

Summary:

622

623

Total Tests: 7

624

Passed: 7

625

Failed: 0

626

Success Rate: 100.0%

627

628

Test Categories:

629

630

Base MCP Protocol: 3 tests (3 passed)

631

WeatherInfo_MCP Specific: 3 tests (3 passed)

632

MCP Inspector: 1 tests (1 passed)

633

634

```
Detailed Results: 635
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```

✓ 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)	686
MCP Spec: Server Features - Tools	687
Details: {	688
"location_created": true,	689
"address": "San Francisco, CA",	690
"latitude": 37.7879363,	691
"longitude": -122.4075201,	692
"has_station_url": true	693
}	694
✓ PASS: [WEATHERINFO_MCP] WeatherInfo_MCP Weather Observation (3.01s)	695
MCP Spec: Server Features - Tools	696
Details: {	697
"observation_retrieved": true,	698
"has_timestamp": true,	699
"has_temperature": true,	700
"has_humidity": true,	701
"observation_keys": [702
"@id",	703
"@type",	704
"elevation",	705
"station",	706
"stationId",	707
"stationName",	708
"timestamp",	709
"rawMessage",	710
"textDescription",	711
"icon"	712
]	713
}	714
✓ PASS: [INSPECTOR] MCP Inspector Availability (0.53s)	715
MCP Spec: Developer Tools	716
Details: {	717
"inspector_available": true,	718
"npx_accessible": true,	719
"help_output_length": 559	720
}	721
	722
Test Coverage:	723
-----	724
☑ Base MCP Protocol Tests:	725
- Connection and Initialization (Base Protocol - Lifecycle)	726
- Tool Manifest Compliance (Server Features - Tools)	727
- Tool Execution Compliance (Server Features - Tools)	728
	729
☑ WeatherInfo_MCP-Specific Tests:	730
- Tool Availability Validation	731
- Location Creation Functionality	732
- Weather Observation Retrieval	733
	734
☑ MCP Inspector Integration:	735
- Inspector Tool Availability	736

- 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:

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- FastMCP Documentation: <https://github.com/modelcontextprotocol/python-sdk>
- MCP Inspector: <https://modelcontextprotocol.io/docs/tools/inspector>
- WeatherInfo_MCP Documentation: [../README.md](https://github.com/modelcontextprotocol/python-sdk/blob/main/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.

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