Smart Monitoring System for Weather and Tsunami Detection (SMSTWD)

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1 System Mission and Objectives

1.1 Mission Statement

The core mission of the Smart Monitoring System for Weather and Tsunami Detection (SMSTWD) is defined as follows:

> *"To save lives, mitigate damage, and offer peace of mind by transforming accurate monitoring into actionable intelligence on natural disasters."*

This mission highlights the monitoring capabilities of our SMSTWD system with a shift from simple data collection to active inferences and life-saving intervention and communication.

1.2 SMSTWD system Philosophy and Vision

The SMSTWD is designed as a technological initiative to enhance natural disaster monitoring, preparedness, response, and resilience. The SMSTWD system philosophy is built upon the integration of multi-modal data sources, specifically satellite imaging, aircraft-based monitoring, and underwater sensor networks to provide a comprehensive, 360-degree view of environmental conditions.

By leveraging state-of-the-art solid-state sensing technologies and advanced machine learning algorithms, the SMSTWD system aims to save lives by minimizing the latency between hazard detection and public alerting. The vision for the SMSTWD system extends beyond immediate detection to include:

- **Proactive Safety:** Moving from reactive warnings to triggering pre-emptive physical safety mechanisms and personalized evacuation routes in the future.
- **Global Accessibility:** Ensuring the SMSTWD system is applicable across diverse geographic regions, from densely populated urban centers to remote coastal villages, with multilingual support.
- **Actionable Intelligence:** Ensuring that every piece of analyzed data is translated into clear, decision-ready information for government agencies and emergency responders.

1.3 Primary Objectives

To achieve its mission, the SMSTWD is defined by the following primary objectives:

1. **Life-Saving Early Warning:** To drastically reduce fatalities by providing accurate, real-time early warnings predicted through state of the art Machine Learning inferences, that enable communities to evacuate or prepare before disaster strikes.
2. **Infrastructure Protection:** To safeguard critical infrastructure (such as power grids and flood gates) by allowing for proactive protective measures based on accurate storm and tsunami trajectory predictions.
3. **Multi-Modal Data Fusion:** To integrate heterogeneous data from atmospheric, oceanic, and seismic domains into a centralized processing unit, utilizing early fusion techniques for robust pattern identification.
4. **Reliable Communication:** To guarantee the dissemination of alerts through multiple channels, including SMS, mobile apps, and government networks ensuring information reaches stakeholders even in volatile environments.
5. **Knowledge Advancement:** To contribute valuable data to scientific research, fostering long-term improvements in meteorology, oceanography, and climate resilience.

1.4 Target Stakeholders

The SMSTWD system supports a diverse ecosystem of stakeholders who rely on this data for decision-making:

- **Primary Beneficiaries:** The general public in coastal and storm-prone regions.
- **Operational Users:** National meteorological agencies, government disaster response agencies, and emergency responders.
- **Secondary Stakeholders:** Insurance firms, cloud service providers, and smart city infrastructure operators.

2 Meta model: System Thinking and Contradictions

The following analysis details the systemic evolution and technical contradictions identified within the SMSTWD system.

To understand the operational environment, we utilized a 9-Box System Thinking approach. Table 1 illustrates the temporal evolution and operational context of the SMSTWD system, mapping its transition from independent monitoring systems in the past to a fully integrated, autonomous future state. This holistic view helps identify the super-system requirements and the necessary sub-system components for effective disaster detection.

Table 1: 9-Box Table for SMSTWD System Evolution

Level	**Past (-5 years)**	**Present (Now)**	**Future (+5 years)**
Super-System (Context)	• National meteorological agencies • Government disaster response agencies • Broadcasters	• Private tech companies and insurance • Cloud service providers • Smart city infrastructure • Smartphones and vehicles	• Autonomous Transport Networks • Autonomous Infrastructure (flood gates, gas lines, and power grids)
System (Function)	• Independent operation of atmospheric, oceanic, and seismic monitoring. • Assimilation of data for situational updates • Detection and alerting of hazards • Issuance of warnings to multiple channels.	• Near real-time ingestion of multi-source data. • Multi-modal data integration • Probabilistic hazard estimation and risk scoring. • Technical dashboards and decision-support systems. • Automated warnings issued to multiple channels.	• Provision of personalized evacuation routes • Triggering of pre-emptive physical safety mechanisms. • High-resolution prediction at street-block level. • Distributed decision-making.

Level	Past (-5 years)	Present (Now)	Future (+5 years)
Sub-systems (Component)	• Satellites (4-8km resolution). • Ocean buoys, slow telemetry. • Seismic networks (land-based). • Standard Doppler radar. • Single-Channel broadcast systems. • Physics-based numerical inference models. • Human forecasters. • Aircraft monitors (radio).	• Satellites (0.5-2km resolution). • Deep sea floor seismic networks. • Faster scanning radar. • Fiber-optic seismic sensing. • ML accelerators for onboard inference. • 5G/WiFi broadcast systems. • AI based multilingual support. • GenAI/Hybrid forecasting models. • Optimised pressure sensors.	• Denser ocean buoy mesh network. • Direct Satellite-to-Sensor communication. • ML models for epicentre radius pinpointing. • Smart IoT bunker guidance. • Nano-Sensors with energy harvesting. • Advanced deep-tectonic seismic sensors. • AR Interfaces for relief. • Advanced AI chips embedded in sensors.

Following the system context analysis, we identified specific technical contradictions that are critical to the performance of the SMSTWD system. We selected these contradictions primarily because they represent the core engineering challenges in balancing speed, accuracy, and energy efficiency in a multi-modal monitoring network. To resolve them, we employed the 2003 TRIZ Matrix and applied the 40 Inventive Principles. The complete matrix is presented in Table 2.

We focused on three key contradictions found in Table 2 and their respective resolutions:

1. Reliability (#35) vs. Energy Used (#17) and Function Efficiency (#24): Fusing all data in a central unit improves speed but risks a single pipeline failure compromising the whole system, leading to wasted compute and energy. To resolve this, we applied **Principle #3 (Local Quality)** to separate data pipelines (atmospheric, oceanic, seismic) to a certain degree, allowing each part of the SMSTWD system to function in conditions most suitable for its operation. Additionally, **Principle #19 (Periodic Action)** was used to configure underwater sensors to transmit data via periodic pulses rather than a continuous stream to save energy.

2. Robustness against Noise (#29) vs. System Complexity (#45): Improving robustness typically requires heavy de-noising, which can drastically increase complexity if every sensor modality requires a unique model. We applied **Principle #6 (Universality)** to create a universal de-noising pipeline. The SMSTWD system uses a single, configurable de-noising algorithm (Preprocess → Band-pass → Wavelet) where only the hyperparameters change based on the sensor type (e.g., underwater vs. aerial).

3. Loss of Time (#26) vs. Reliability (#35): Mechanical components in sensors are slow and prone to wear. Using **Principle #28 (Mechanics Substitution)**, the SMSTWD system replaces mechanical water flow spinners with solid-state sensing technologies, such as ultrasonic flow detectors. This substitution improves reaction time and eliminates moving parts, simultaneously enhancing reliability and speed.

Table 2: Complete TRIZ Contradiction Matrix for SMSTWD

Worsening → / Improving ↓	**Amount of Information (#11)**	**Loss of information (#28)**	**System Complexity (#45)**	**Loss of Time (#26)**	**Reliability (#35)**	**Ability to detect/Measure (#47)**	**Noise (#29)**	**Energy Used (#17)**	**Compatibility/connectability (#33)**	**Function Efficiency (#24)**	**Security (#37)**
Amount of Information (#11)		15 19 7 32			10 24 13 25						
Loss of information (#28)	2 7 24 3		6 25 13 24	24 28 32 2			10 1 24 36				
Loss of time (#26)		24 28 32 2	28 21 6 10		**35 10 3 14**	37 10 18 32				2 28 26 9	

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Worsening → / Improving ↓	**Info (#11)**	**Loss (#28)**	**System (#45)**	**Time (#26)**	**Relia (#35)**	**Detect (#47)**	**Noise (#29)**	**Energy (#17)**	**Connect (#33)**	**Effic (#24)**	**Sec (#37)**
System Complexity (#45)					3 13 28 1	28 10 32 37			6 28 13 35		
Reliability (#35)			5 35 13 33				**35 19 3 1**		**15 3 19 35**		
Ability to detect/Measure (#47)			28 37 10 15				35 19 2 24				
Measurement Precision (#48)				24 28 2 10			10 24 5 3				
Noise (#29)			**6 13 1 24**	35 28 19 35						17 15 31 3	
Energy Used (#17)					40 13 35 19	32 15 1 9				2 19 15 3	
Compatibility/connectability (#33)			28 24 13 12							24 10 28 25	
Function Efficiency (#24)		3 4 19 15									
Security (#37)			2 6 4 17 13	26 28 25 2							

3 Requirements and Use cases

This section details the specific requirements governing the SMSTWD system. These requirements are categorized into Functional (FR), Non-Functional (NFR), and Safety requirements. To ensure a robust system architecture, we utilized both specific derivation techniques and TRIZ inventive principles to define these requirements.

3.1 Derivation of Requirements

Several requirements were derived from high-level operational goals and technical contradictions identified in the system analysis.

Derived Requirements: Derived requirements bridge the gap between high-level user needs and specific system behaviors. For instance, the high-level goal to issue real-time SMS warnings necessitated the derived requirement for the SMSTWD system to cross-reference predicted impact zone coordinates with registered user locations. Similarly, the requirement for multilingual support led to the derived need for a configurable database mapping geographical regions to designated primary languages.

TRIZ-Based Requirements: We utilized the TRIZ Contradiction Matrix to resolve three critical technical conflicts identified in the system design: Reliability (#35) vs. Energy Used (#17), Robustness against Noise (#29) vs. System Complexity (#45), and Loss of Time (#26) vs. Reliability (#35).

To address these, we selected five relevant Inventive Principles (#3, #6, #19, #28, #35) and mapped them to specific technical requirements:

- **Universality (Principle #6):** To resolve the conflict between noise robustness and complexity, we defined a requirement for a single, configurable de-noising algorithm that is applicable to all sensor types (aerial, underwater, satellite), differing only by configuration parameters.
- **Local Quality (Principle #3):** To balance energy efficiency with reliability, we required that sensor nodes use non-uniform power profiles specific to their local environment (e.g., deep-sea nodes operate differently than surface buoys).
- **Mechanics Substitution (Principle #28):** To address the loss of time and reliability issues caused by mechanical wear, the system requires the use of solid-state sensing technologies (such as ultrasonic flow detectors) instead of mechanical moving parts.

– **Periodic Action (Principle #19):** To further resolve the Reliability vs. Energy Used contradiction, we mandated that underwater sensors transmit data using periodic pulses (e.g., every 10-30 seconds) rather than a continuous stream, switching to continuous mode only when hazards are detected.
– **Parameter Changes (Principle #35):** To optimize system response, we applied this principle to require the system to dynamically alter its internal risk scoring parameters and detection thresholds in real-time based on the current environmental state (e.g., shifting from "calm" to "volatile" modes).

3.2 Functional Requirements (FR)

The Functional Requirements describe the specific behaviors and functions the SMSTWD system must perform. The structural relationship of these requirements is illustrated in Figure 1.

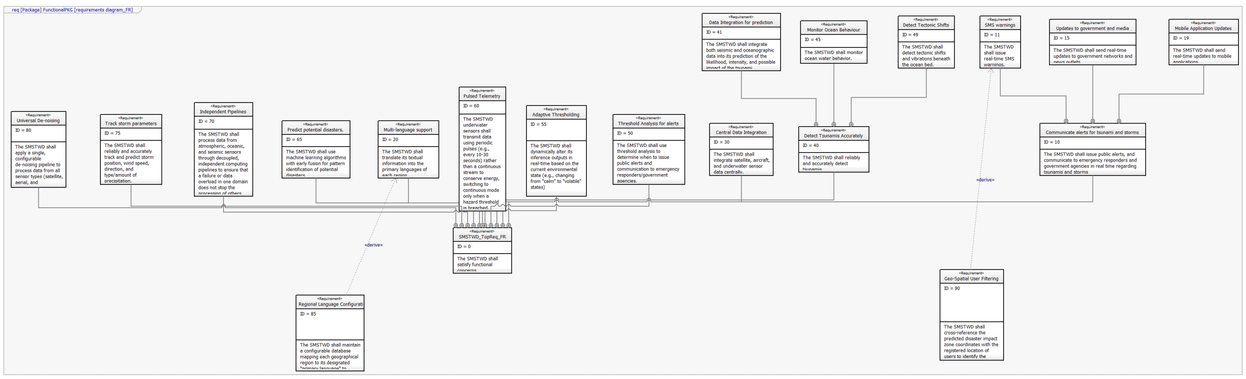

Fig. 1. SysML Functional Requirements Diagram

– The SMSTWD system shall issue public alerts and communicate to emergency responders and government agencies in real-time regarding tsunamis.
– The SMSTWD system shall issue real-time SMS warnings.
– The SMSTWD system shall send real-time updates to mobile applications, government networks, and news outlets.
– The SMSTWD system shall communicate to emergency responders and meteorologists in real-time regarding storms.
– The SMSTWD system shall translate its textual information into the primary languages of each region.
– The SMSTWD system shall integrate satellite, aircraft, and underwater sensor data centrally.
– The SMSTWD system shall use machine learning algorithms with early fusion for pattern identification of potential disasters.
– The SMSTWD system shall use threshold analysis to determine when to issue public alerts.
– The SMSTWD system shall reliably and accurately detect tsunamis by detecting tectonic shifts, vibrations beneath the ocean bed, and monitoring ocean water behavior.
– The SMSTWD system shall integrate both seismic and oceanographic data into its prediction of the likelihood, intensity, and possible impact of tsunamis.
– The SMSTWD system shall reliably and accurately track and predict storm position, wind speed, direction, and precipitation.
– The SMSTWD system shall apply a single, configurable de-noising algorithm to process data from all sensor types.
– The SMSTWD system shall process data from atmospheric, oceanic, and seismic sensors through decoupled, independent computing pipelines.
– The SMSTWD system shall cross-reference the predicted disaster impact zone coordinates with the registered location of users to identify the specific subset of recipients for SMS warnings.
– The SMSTWD system shall maintain a configurable database mapping each geographical region to its designated "primary language".

3.3 Non-Functional Requirements (NFR)

The Non-Functional Requirements define the system's quality attributes, such as reliability, efficiency, and interpretability. These are visualized in Figure 2.

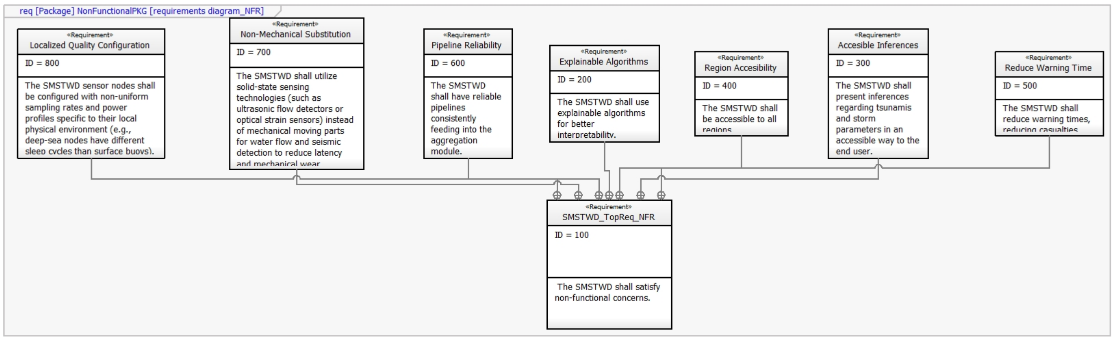

Fig. 2. SysML Non-Functional Requirements Diagram

- The SMSTWD system underwater sensors shall transmit data using periodic pulses (e.g., every 10-30 seconds) rather than a continuous stream, only switching to continuous mode when a hazard threshold is breached.
- The SMSTWD system shall dynamically alter its internal risk scoring parameters and detection thresholds in real-time based on the current environmental state.
- The SMSTWD system shall utilize solid-state sensing technologies instead of mechanical moving parts for water flow and seismic detection.
- The SMSTWD system sensor nodes shall be configured with non-uniform sampling rates and power profiles specific to their local physical environment.
- The SMSTWD system shall have reliable pipelines consistently feeding into the aggregation module.
- The SMSTWD system shall use explainable algorithms for better interpretability.
- The SMSTWD system shall present inferences regarding tsunamis and storm parameters in an accessible way to the end user.
- The SMSTWD system shall reduce warning times to minimize casualties.
- The SMSTWD system shall be accessible to all regions.

3.4 Safety Requirements

Safety constraints are critical to prevent false positives and environmental harm. Figure 3 depicts the safety requirement hierarchy.

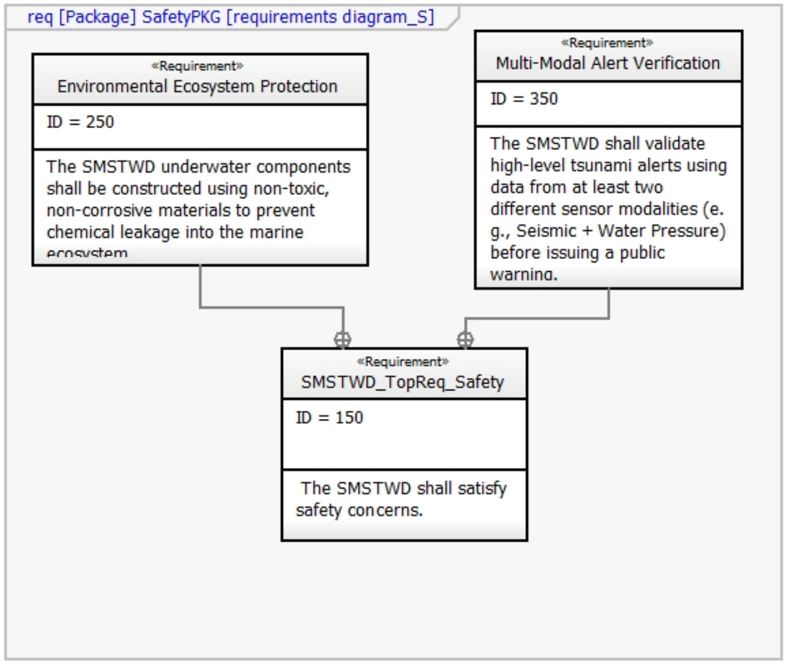

Fig. 3. SysML Safety Requirements Diagram

- The SMSTWD system shall validate high-level tsunami alerts using data from at least two different sensor modalities (e.g., Seismic + Water Pressure) before issuing a public warning.
- The SMSTWD system underwater components shall be constructed using non-toxic, non-corrosive materials to prevent chemical leakage into the marine ecosystem.
- The SMSTWD system shall perform a self-diagnostic "heartbeat" check on all critical sensors every 60 seconds to immediately detect system failures.

4 System Context and Environment

This section defines the operational boundaries of the Smart Monitoring System for Weather and Tsunami Detection (SMSTWD) and its interactions with the wider environment. The system operates as a central intelligent hub within a complex ecosystem of diverse sensor networks, end-users, and external computational infrastructure.

The high-level interactions between the SMSTWD and these external entities are illustrated in the System Context Diagram shown in Figure 4.

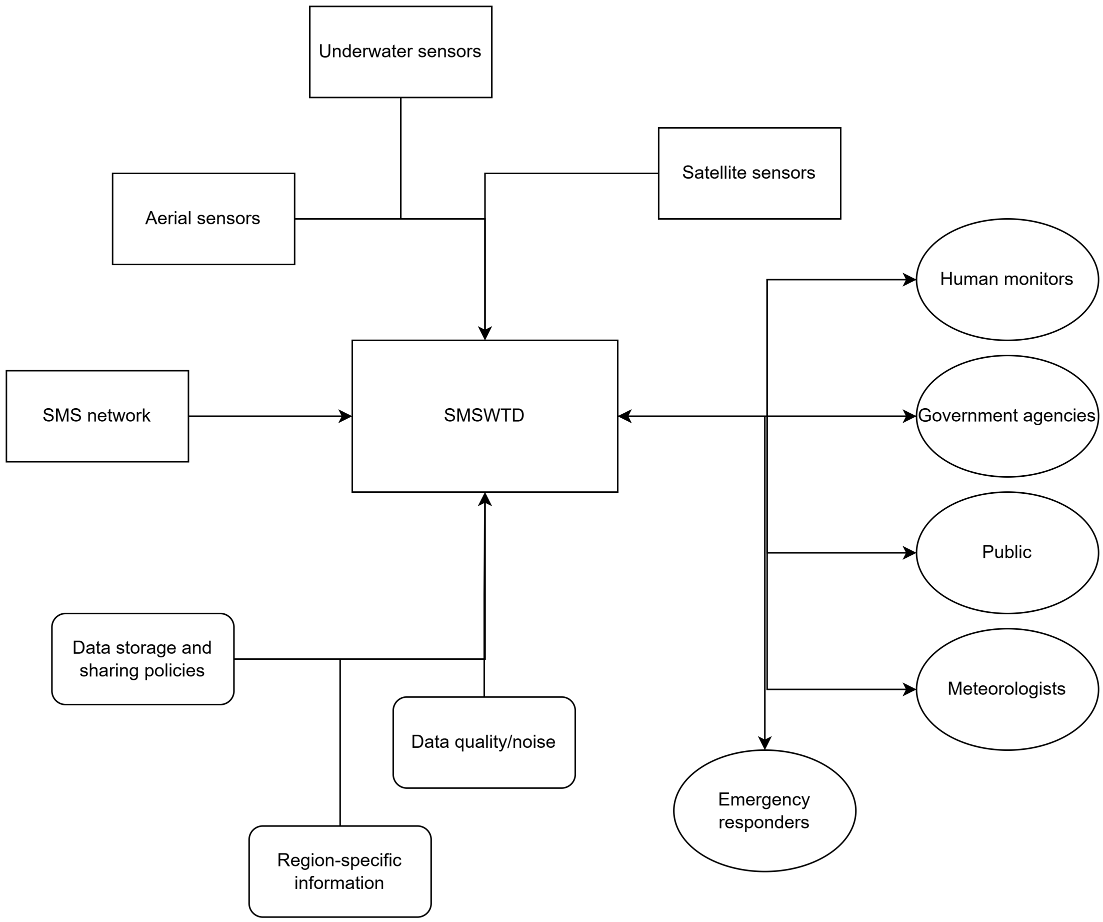

Fig. 4. SMSTWD System Context Diagram illustrating boundaries, actors, and constraints.

4.1 System Boundaries

As depicted in Figure 4, the operational boundary of the SMSTWD encapsulates the core logic for data ingestion, multi-modal sensor fusion, probabilistic risk scoring, and alert generation. The physical sensor hardware (satellites, buoys, seismometers) are considered external data sources that feed into the system boundary. Similarly, human users and external infrastructure systems are actors outside the boundary that receive processed information or provide computational support.

4.2 External Entities and Interactions

The environment surrounding the SMSTWD can be categorized into three primary groups of external entities: Sensor Inputs, User Outputs, and External Infrastructure.

Heterogeneous Sensor Inputs The SMSTWD relies on real-time data ingestion from diverse physical environments to form a comprehensive situational awareness model. These external systems provide the raw data necessary for fusion:

- **Satellite Systems:** Provide high-resolution imagery (0.5-2km resolution) and large-scale meteorological data.
- **Oceanic Sensor Networks:** Deep-sea buoys and sensors providing telemetry on water pressure, flow direction, and tidal wave characteristics.

- **Seismic Networks:** Land-based and submarine sensors detecting ground vibrations and tectonic plate movements.
- **Atmospheric Sensors:** Localized weather stations providing data on pressure, temperature, and wind speeds.

User Outputs and Stakeholders The primary purpose of the system is to deliver actionable intelligence to human actors:

- **General Public:** Receives time-critical emergency alerts via multiple broadcast channels (SMS, apps) to facilitate evacuation.
- **Government Agencies:** Receive detailed probabilistic risk scores, technical dashboards, and decision-support data to coordinate operational disaster response.

External Infrastructure Support To maintain high availability and processing power, the SMSTWD integrates with external technical systems:

- **Cloud Service Providers:** Offer scalable external storage for historical data and high-performance computing resources for running complex AI/ML inference models.
- **Smart City Infrastructure & Autonomous Transport Networks:** Future-facing integrations intended to receive automated triggers from the SMSTWD to activate flood gates, shut down gas lines, or reroute autonomous traffic without human intervention.

4.3 Environmental Conditions

The SMSTWD must operate reliably within highly volatile and physically aggressive environments. The system context includes:

- **Harsh Physical Environments:** Underwater sensors and buoys are exposed to high pressure, corrosion, and turbulence in deep-sea environments.
- **Dynamic States:** The environment transitions rapidly between "calm" and "volatile" states, requiring the system to dynamically adapt its sampling rates and risk scoring parameters in real-time.
- **Remote Locations:** Many sensor nodes are located in remote coastal villages or open oceans where physical maintenance is difficult, necessitating high autonomy and energy harvesting capabilities.

4.4 System Constraints and Regulations

The system operates under strict technical and legal constraints that influence its architecture and data handling procedures.

Technical Constraints

- **Data Quality and Noise:** The system ingests highly noisy data from heterogeneous sources. Signals from underwater and aerial sensors often contain environmental interference, requiring heavy de-noising and domain-specific tuning before processing can occur.
- **Latency Requirements:** To prevent loss of life, the system must process data and issue warnings in near real-time, requiring minimized latency between detection and alert dissemination.

Laws and Regulations

- **Data Storage and Privacy:** As the system interacts with mobile applications and personal devices for alerts, it must adhere to data privacy laws regarding the storage and handling of user location data.
- **Government Compliance:** The system functions as a critical alert mechanism for national safety. It must comply with government regulations regarding the format, timing, and validation of public emergency broadcasts to prevent false alarms and panic.
- **Sharing Policies:** Inter-agency data sharing policies dictate how raw sensor data and risk scores are distributed between national meteorological agencies and private tech companies.

5 System Architecture and User Model

This section details the structural design and internal behavioral flows of the SMSTWD. The system architecture is defined via a Block Definition Diagram (BDD), illustrating the decomposition into major subsystems. The internal interactions and data processing pipelines that realize the system's function are detailed in the Internal Block Diagram (IBD).

5.1 System Architecture (Block Definition Diagram)

The high-level modular structure of the SMSTWD is presented in the Block Definition Diagram in Figure 5. The architecture is designed around the principle of separation of concerns, ensuring that data acquisition, processing, alerting, and power management are handled by distinct, specialized subsystems.

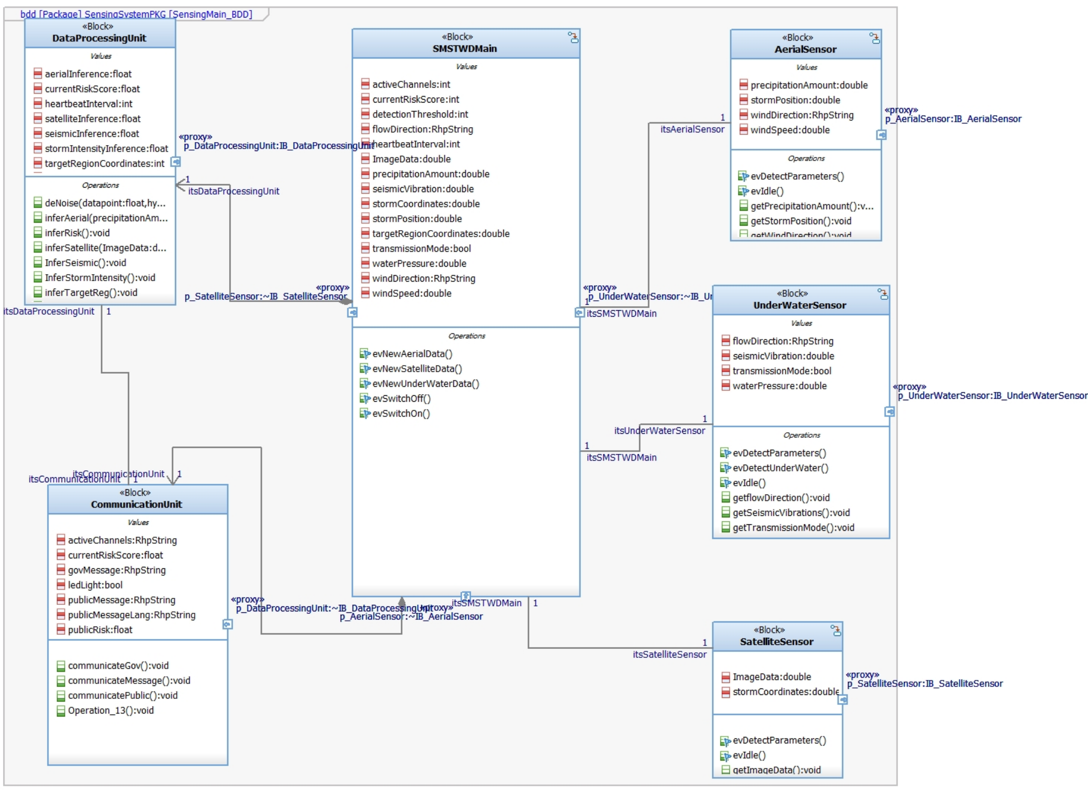

Fig. 5. Block Definition Diagram (BDD) depicting the high-level architecture and subsystems of the SMSTWD.

As shown in Figure 5, the central **SMSTWD System** is composed of four primary subsystems:

– **Monitoring Subsystem:** This is the interface layer between external physical sensors and the internal processing logic. It is responsible for ingesting raw data from diverse sources—including Satellite Systems, Oceanic Sensor Networks, and Seismic Networks. As established in the Contradiction Matrix analysis, this subsystem includes universal pre-processing modules to handle heavy de-noising at the ingestion point.

– **Data Processing Unit (DPU):** The computational core of the system. The DPU is tasked with ingesting preprocessed multi-modal data. It houses the logic for "Sensor Fusion" to create a unified environmental model and executes "AI/ML Risk Scoring" algorithms to determine the probability and severity of impending hazards in near real-time.

- **Alerting and Communication Subsystem:** This subsystem acts as the output interface to external actors. It receives risk scores and translates them into actionable formats for two distinct categories: "Multi-channel Alerts" for human stakeholders (General Public, Government Agencies) and "Automated Triggers" for External Infrastructure (e.g., smart city flood gates).
- **Power Management Subsystem:** Given that many sensor nodes operate in remote locations, this critical subsystem manages energy harvesting (e.g., from tidal waves or solar) and ensures a stable, regulated power supply to all other active subsystems.

5.2 Internal Interactions (Internal Block Diagram)

While the BDD defines *what* the components are, the Internal Block Diagram (IBD) in Figure 6 illustrates *how* these components interact to transform raw environmental data into actionable intelligence.

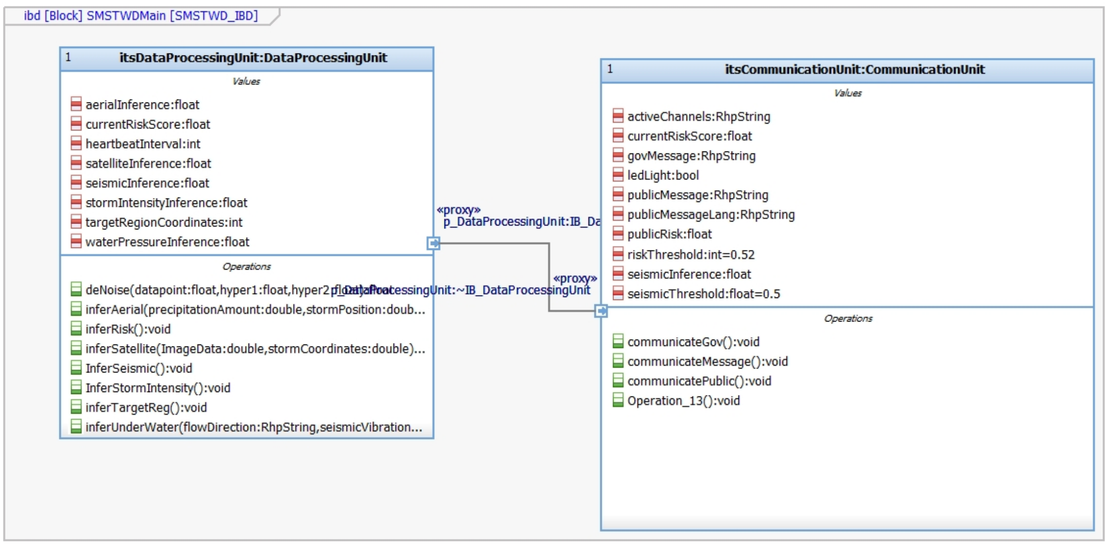

Fig. 6. Internal Block Diagram (IBD) illustrating the data flow and processing pipeline within the SMSTWD.

The operational flow represented in Figure 6 follows a sequential pipeline:

1. **Data Acquisition and Preprocessing:** Raw Sensor Data is streamed from external sensors into the main monitoring Subsystem. Here, initial signal is processed and denoised resulting in standardized "Preprocessed Data."
2. **Fusion and Decision Making:** The Preprocessed Data is routed to the **Data Processing Unit**. Within the DPU, the "Sensor Fusion" block integrates the heterogeneous data streams. The fused data is then passed through "AI/ML Risk Scoring" ML algorithms, which generates definitive Risk Scores & Trigger Signals.
3. **Alert Dissemination:** The generated scores and signals are sent to the **Alerting and Communication Subsystem**. This subsystem routes the information appropriately: high-priority alerts are broadcast via multiple channels to human stakeholders, while specific machine-readable triggers are sent to autonomous infrastructure.

6 Behavioral Analysis

This section details the dynamic behavior of the SMSTWD. We utilize SysML State Machine Diagrams to define the lifecycle and operational states of the system's components, and a Sequence Diagram to illustrate the time-ordered interaction between sensors, the Data Processing Unit (DPU), and the Communication Unit (CU).

6.1 State Machine Modeling

The system's behavior is event-driven. The main controller manages the overall system state, while independent sensors operate in parallel orthogonal states to capture multi-modal data.

Main System Lifecycle The high-level behavior of the SMSTWD is depicted in Figure 7.

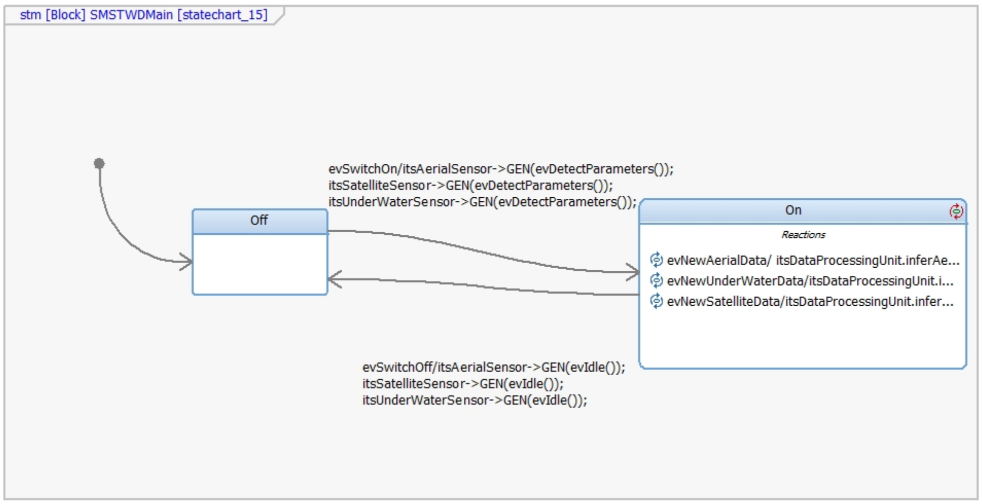

Fig. 7. State Machine Diagram for the SMSTWD Main System.

As shown in Figure 7, the system transitions from `Off` to `On` via the `evSwitchOn` event. Upon entry into the `On` state, the system triggers the `evDetectParameters()` event on all connected sensors (Aerial, Satellite, and Underwater), initializing the global monitoring process. Inside the `On` state, the system acts as a listener; it waits for data events (e.g., `evNewAerialData`, `evNewUnderwaterData`) and immediately routes this payload to the `itsDataProcessingUnit` for inference.

Sensor Behaviors and Parallelism Each sensor subsystem utilizes orthogonal regions to perform tasks concurrently.

- **Aerial Sensor:** (Figure 8) Captures four distinct data points simultaneously: `precipitationAmount`, `stormPosition`, `windDirection`, and `windSpeed`. The statechart shows these parameters being updated in parallel loops (with varying timer intervals like 5000ms or 7000ms), ensuring a continuous stream of atmospheric data.
- **Satellite Sensor:** (Figure 9) Operates two parallel regions: one for capturing `ImageData` and another for tracking `stormCoordinates`. This separation allows image processing (which may be slower) to occur without blocking coordinate tracking.
- **Underwater Sensor:** (Figure 10) Monitors `waterPressure`, `seismicVibration`, and `flowDirection`. Crucially, it includes a specific state for `transmissionMode`. This state governs the sensor's communication behavior, adhering to the TRIZ requirement to periodically sleep or pulse data transmission to conserve energy in remote deep-sea locations.

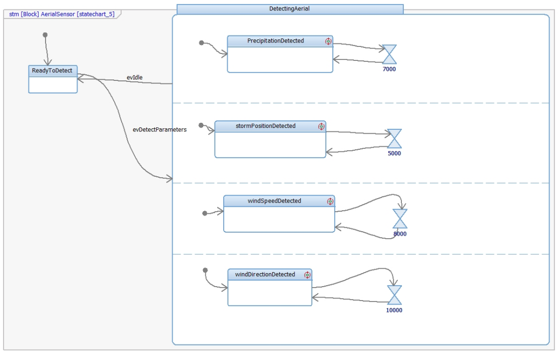

Fig. 8. Aerial Sensor Statechart.

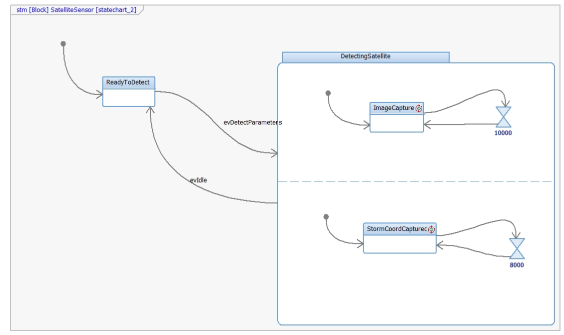

Fig. 9. Satellite Sensor Statechart.

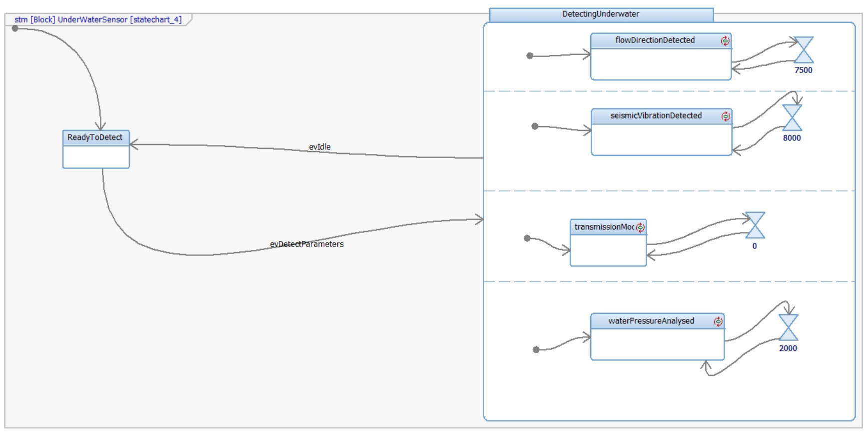

Fig. 10. Underwater Sensor Statechart highlighting the transmission mode.

6.2 Operational Sequence and Data Logic

The end-to-end data flow is illustrated in the Sequence Diagram (Figure 11), taking the Aerial Sensor scenario as a representative example.

The sequence of operations proceeds as follows:

1. Data Ingestion and Inference (DPU) The **Data Processing Unit (DPU)** acts as a subsystem within the main block. It receives raw inputs from the sensors, including the diagnostic signal confirming the sensor is transmitting correctly.

- **Input:** The DPU accepts multi-modal inputs: Wind Speed/Direction, Storm Position, Precipitation (Aerial); Pressure, Seismic, Flow (Underwater); Coordinates, Images (Satellite).
- **Inference:** The DPU runs this data through an internal machine learning model. It performs 'deNoising' (as per the BDD operations) and generates specific predictions: `stormIntensity`, `waterPressureInference`, and `seismicInference`.
- **Risk Scoring:** Based on these predictions, the DPU calculates a consolidated `currentRiskScore`.

2. Communication Logic (CU) The inferred data and risk scores are passed to the **Communication Unit (CU)**, which manages stakeholder interaction based on strict logic:

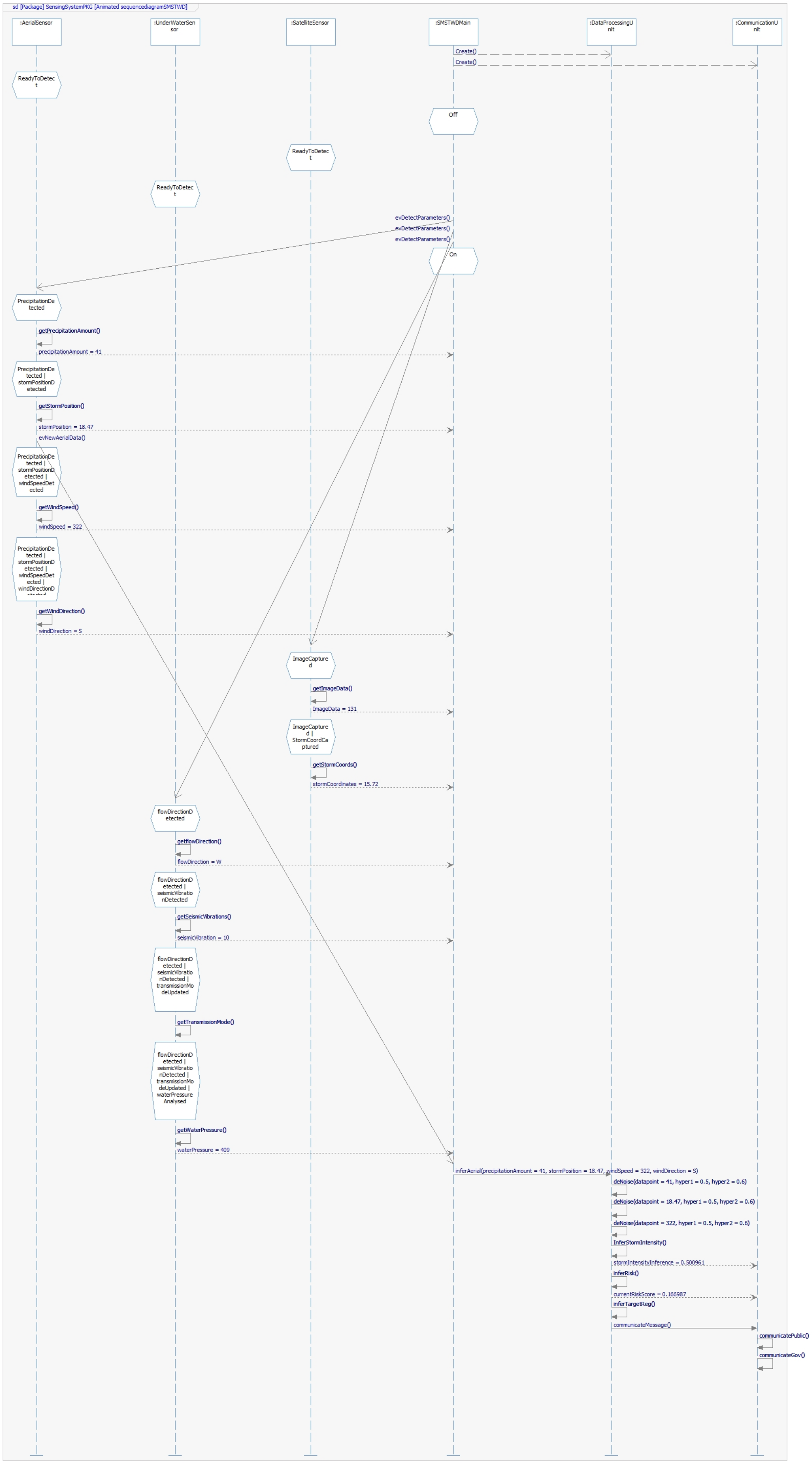

Fig. 11. Sequence Diagram illustrating the Aerial Sensing and Decision Logic.

- **Government Communication:** The CU maintains a constant link with government agencies.
  - *Normal State:* If the risk score is below the threshold, the system sends a heartbeat message: "Everything is Fine."
  - *Alert State:* If `stormIntensity`, `waterPressure`, or `seismicActivity` cross predefined thresholds, the message changes dynamically to indicate the specific hazard (Tsunami or Storm). Simultaneously, a visual signal (represented by `ledLight`) is triggered to indicate high risk.
- **Public Communication:** Unlike the constant government stream, public alerts are event-based.
  - *Multichannel:* Alerts are disseminated via SMS network and mobile application updates.
  - *Localization:* Addressing the requirement for a multi-region system, the CU includes a `publicMessageLang` property, ensuring the alert is translated into the region-specific language before dissemination.
  - *Risk Probability:* The risk score is only shown to public when parameters cross their threshold to prevent unnecessary panic.

6.3 User Interface and Interaction

To validate the system behavior and visualize the interaction between internal logic and stakeholder outputs, a Graphical User Interface (GUI) was developed. This interface serves as a real-time dashboard for monitoring sensor health, inference confidence, and alert dissemination status.

The GUI behavior dynamically adapts to the system's internal state, as demonstrated in the following scenarios.

Baseline Operation and Diagnostics Figure 12 illustrates the system in its nominal operating state.

Fig. 12. GUI displaying nominal "Everything is Fine" state with active diagnostics.

In this state:

- **Sensor Diagnostics:** The "Diagnostic LEDs" for Aerial, Underwater, and Satellite sensors are illuminated (Red/Active), fulfilling the safety requirement for a continuous heartbeat check.
- **Government Output:** The 'Government/Authorities Message' display reads "Everything is Fine," indicating that while data is flowing, no risk thresholds have been breached.
- **Visual Instrumentation:** Key parameters such as Wind Speed (digital counter), Storm Position (xy coordinates), and Water Pressure (gauge) are visualized in real-time to allow human operators to verify sensor precision.

Fig. 13. GUI Alert State triggering "Emergency Protocol 1" due to Storm Intensity threshold breach.

Storm Detection Scenario When the system detects atmospheric anomalies, the interface updates immediately to reflect the specific hazard type. Figure 13 shows the system response when the 'ML Storm Intensity Inference' crosses its defined threshold.

Key behavioral changes include:

– **Specific Alerting:** The Government Message updates to "Possible storm detected; enact emergency protocol 1," providing actionable intelligence rather than raw data.
– **Public Warning:** The SMS and Mobile App alert fields display "Possible storm detected; please remain indoors," verifying the requirement for multi-channel dissemination.
– **Threshold Logic:** The 'Threshold Analysis' panel visually indicates that the Storm Intensity value (0.501) has exceeded the set limit, triggering the state transition.

Tsunami Detection Scenario Figure 14 demonstrates the validation of a multi-modal high-risk event.

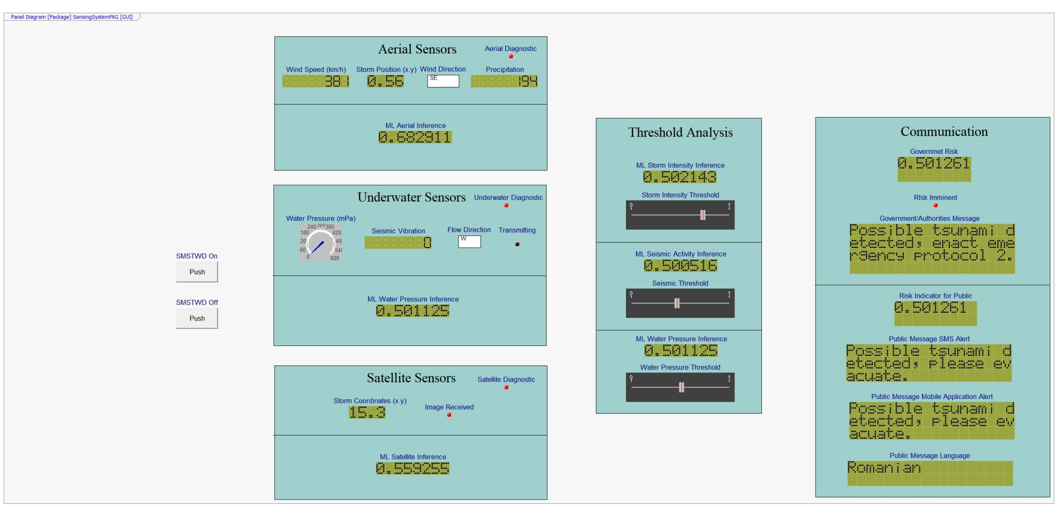

Fig. 14. GUI Tsunami Alert triggered by dual-threshold breach (Seismic + Water Pressure).

This scenario verifies the critical safety requirement to validate high-level tsunami alerts using at least two different sensor modalities:

- **Dual Confirmation:** The GUI shows that both 'ML Seismic Activity Inference' and 'ML Water Pressure Inference' have crossed their respective thresholds.
- **Multilingual Support:** The 'Public Message Language' field displays "Romanian," confirming the system's ability to identify the target region's primary language and prepare alerts accordingly.
- **Urgent Messaging:** The public alerts escalate to "Possible tsunami detected; please evacuate," differentiating the response from the storm scenario.

7 Conclusion

The Smart Monitoring System for Weather and Tsunami Detection (SMSTWD) represents a significant advancement in disaster management technology. By integrating heterogeneous data sources like satellite, aerial, and underwater into a unified processing framework, the system addresses the critical need for real-time, actionable intelligence in the face of natural disasters.

Throughout this project, we applied a rigorous systems engineering approach to define a robust and scalable architecture. The utilization of the **9-Box System Thinking model** allowed us to contextualize the system's evolution, ensuring the design is future-proofed for integration with autonomous infrastructure and smart cities. Furthermore, the application of **TRIZ Inventive Principles** provided a structured method to resolve complex engineering contradictions, specifically balancing the trade-offs between system reliability, energy efficiency, and operational complexity in harsh environments.

The architectural design, formalized through SysML Block Definition and Internal Block Diagrams, establishes a modular structure capable of handling high-throughput data fusion and probabilistic risk scoring. The validation of system behavior via State Machine diagrams and the Graphical User Interface demonstrates the SMSTWD's ability to dynamically adapt to changing risk levels, enforce safety protocols through dual-sensor validation, and effectively communicate alerts across multiple languages and channels.

Ultimately, the SMSTWD successfully meets its primary mission, i.e to bridge the gap between raw environmental data and public safety, transforming accurate monitoring into life-saving alerts that protect both communities and critical infrastructure.

References

1. Assignment Deliverables for SMSTWD, 2025.
2. Lecture notes and materials by Prof. Dr.Ion Barosan