Long-duration Autonomy for Open Ocean Exploration: Preliminary Results & Challenges

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Motivations

- The warming of the planet by anthropogenic causes: a threat to biodiversity.
- Ship-based methods are discrete, release CO_2 and are limited in scaling across space and time.
- Current robotic observation platforms are constrained by proximity to ship or shore and onboard energy [1].
- Need of tools capable of *persistently* observing phenomena at different spatio-temporal scales, in harsh and remote environments [2].

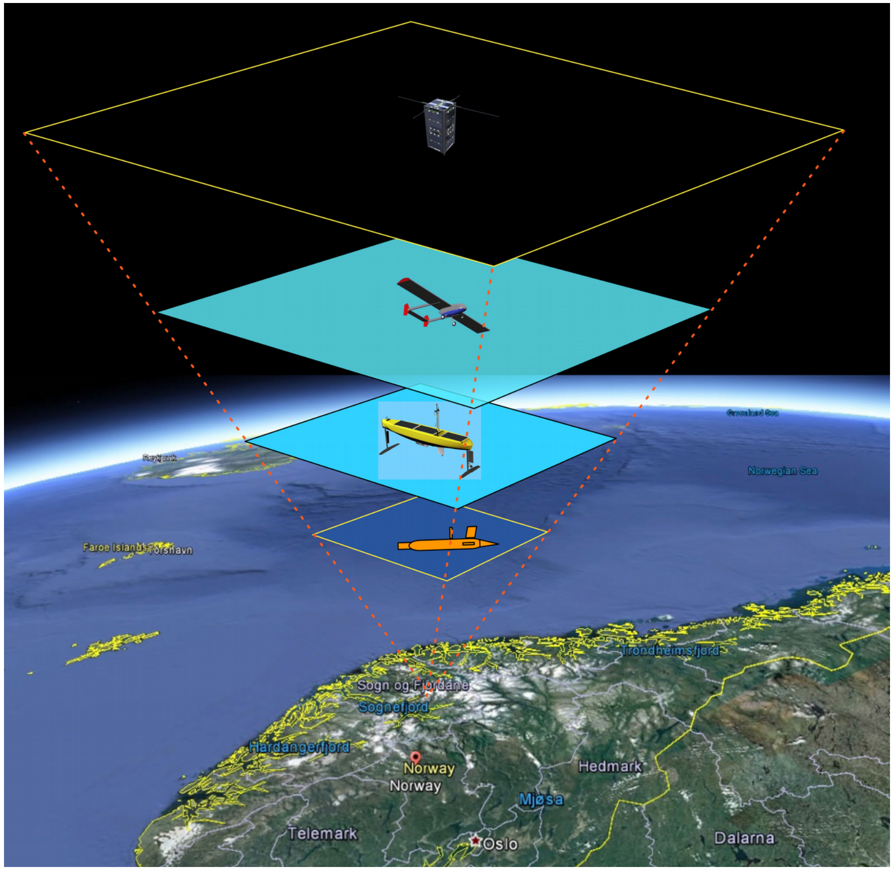

Fig. 1: Coordinated observations that encompasses space, aerial, surface and underwater platforms.

Objectives

- Replace ship-based observation with recent innovations in Robotics and Artificial Intelligence (AI).
- Monitor meso-scale dynamic processes with mobile platforms equipped with a wide-range payload (Fig. 2).
- Extend current efforts with data driven operations based on shore-side models.
- Equip an ASV with an advanced AI decision-engine capable of autonomously generate its goals based on online resources computation, continuous risk evaluation and models computed on shore.

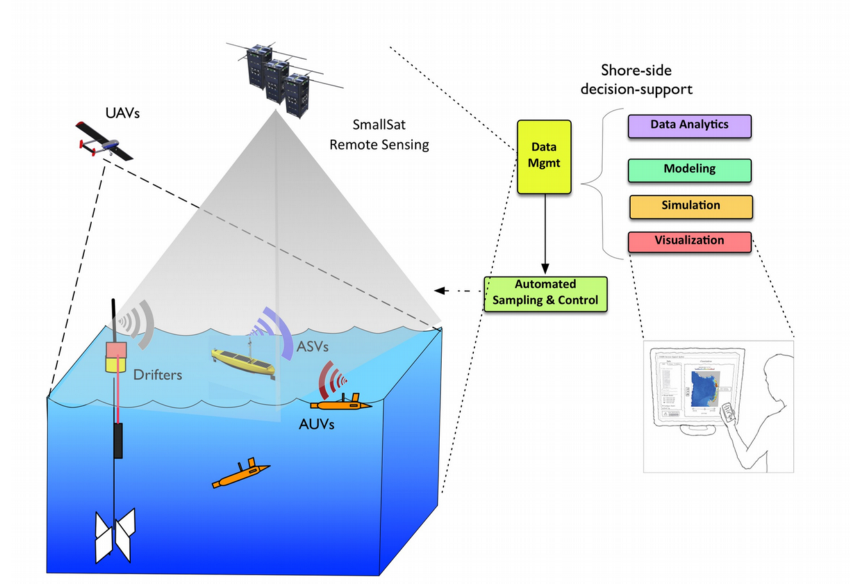

Fig. 2: Envisioning the need of coordinated autonomous robotic platforms for environmental monitoring and exploration [3].

Methods – Automated Planning & Execution

- **Goal**: generate plans for desired outcomes or intents.
- It synthesizes a sequence of actions transforming the initial state of a robot into a state that satisfies predefined goals [4].
- A Knowledge Engineering (KE) process transforms the real world into a symbolic representation such that the model is consistent and accurate [5].

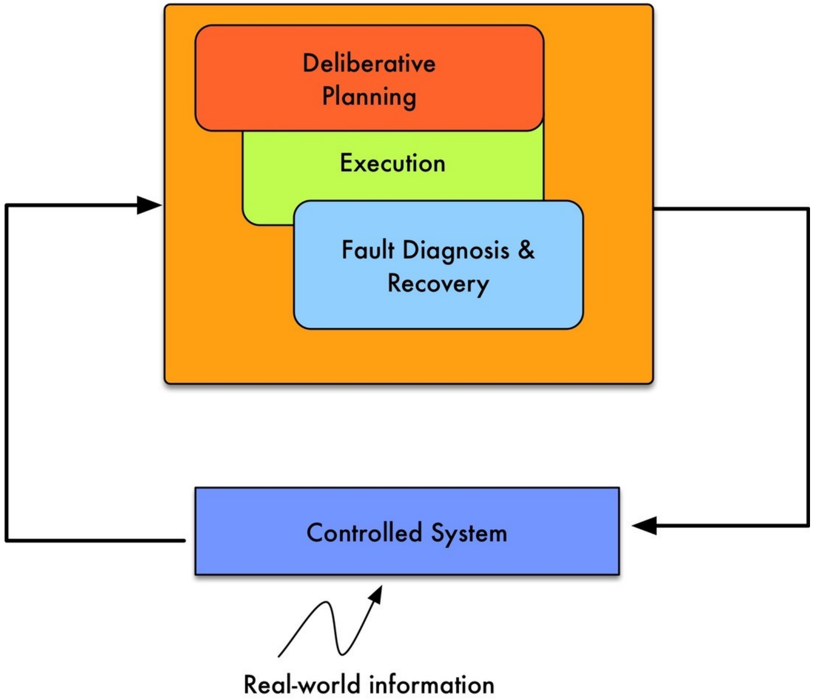

Fig. 3: Continuous deliberation drives the robotic agent in the real-world, that in turn provides feedback, acquired through sensors to support the deliberation process.

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Methods – Automated Planning & Execution

- The Teleo-Reactive EXecutive (T-REX) [6] is the only deliberative control framework in operational oceanography.
- Sustained and continuous autonomous control is still an open challenge.
- Generated plans would likely be invalid during sustained exploration: self-awareness, robustness to failures and risks and autonomous goal generation are needed.

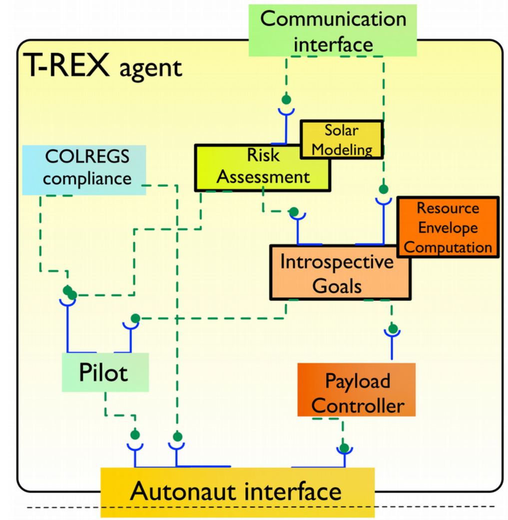

Fig. 4: T-REX agent high-level block diagram.

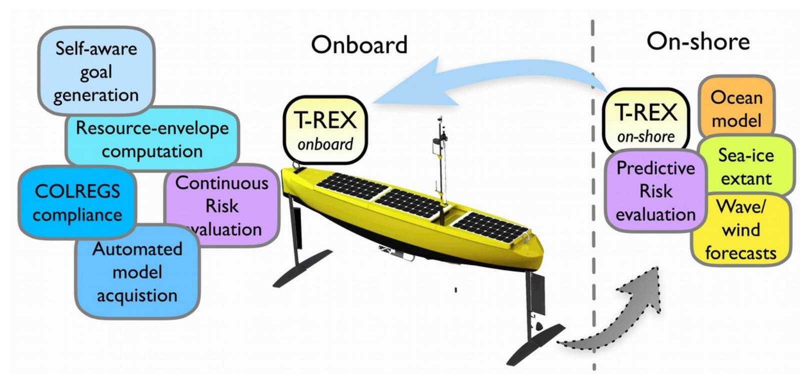

Fig. 5: Elements interacting with T-REX, a deliberate planning/scheduling framework.

AutoNaut – A green-energy ASV

- Wave-propelled ASV relying on solar energy to drive propulsion and scientific payload [7].
- Innovative propulsion system relying on waves intensity and ocean state.
- Vehicle suitable for long-duration missions without human intervention.
- Bottom-up design of its navigation control and communication system, targeting robustness and endurance [8].

Fig. 6: AutoNaut during operations in Trondheimsfjord.

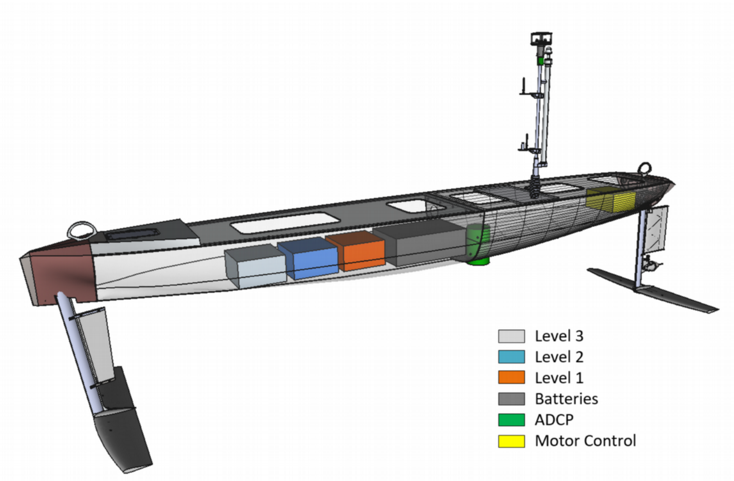

Fig. 7: AutoNaut 3D model.

System Architecture

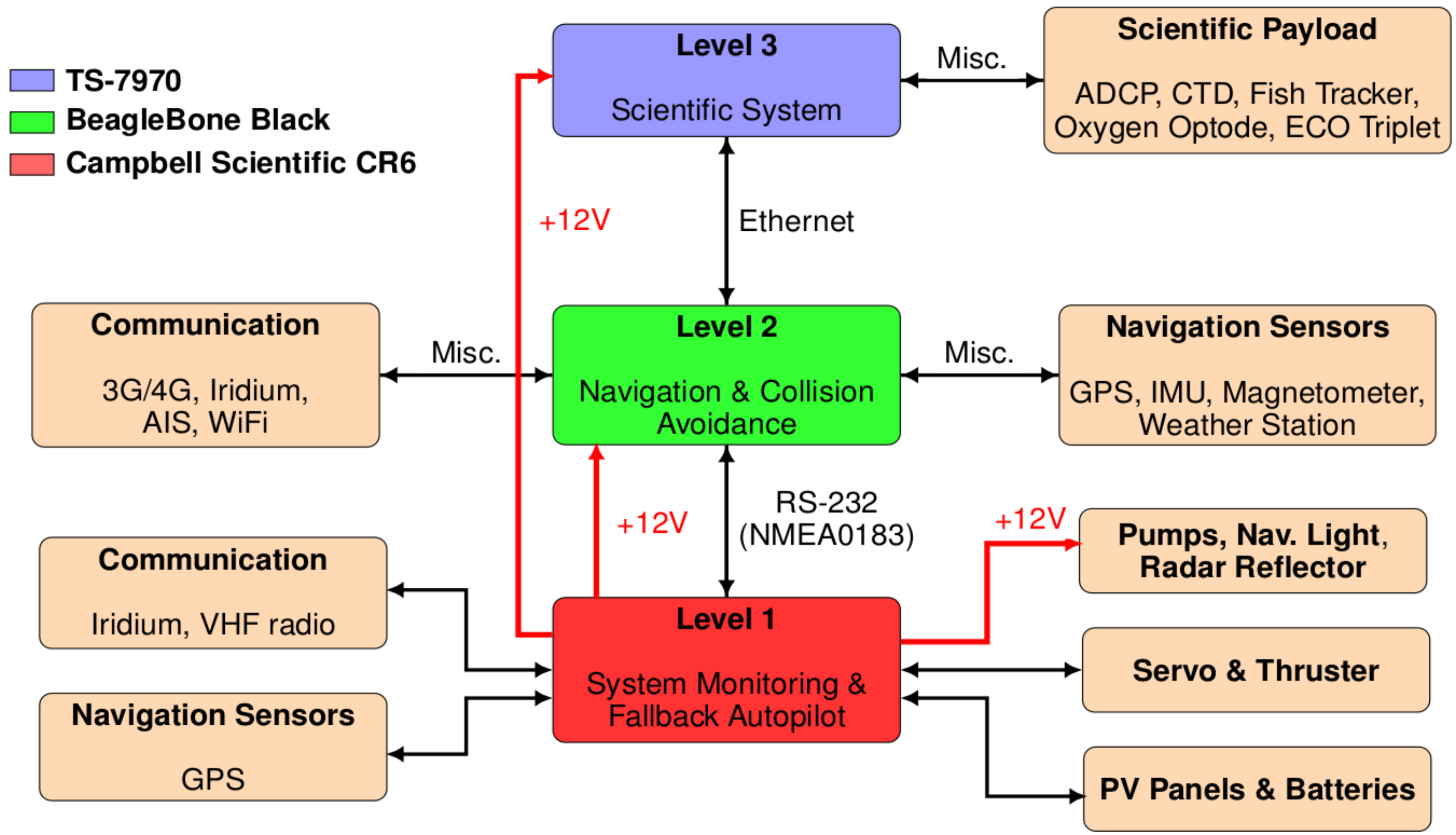

Fig. 8: Hardware layered architecture [9].

Communication Means

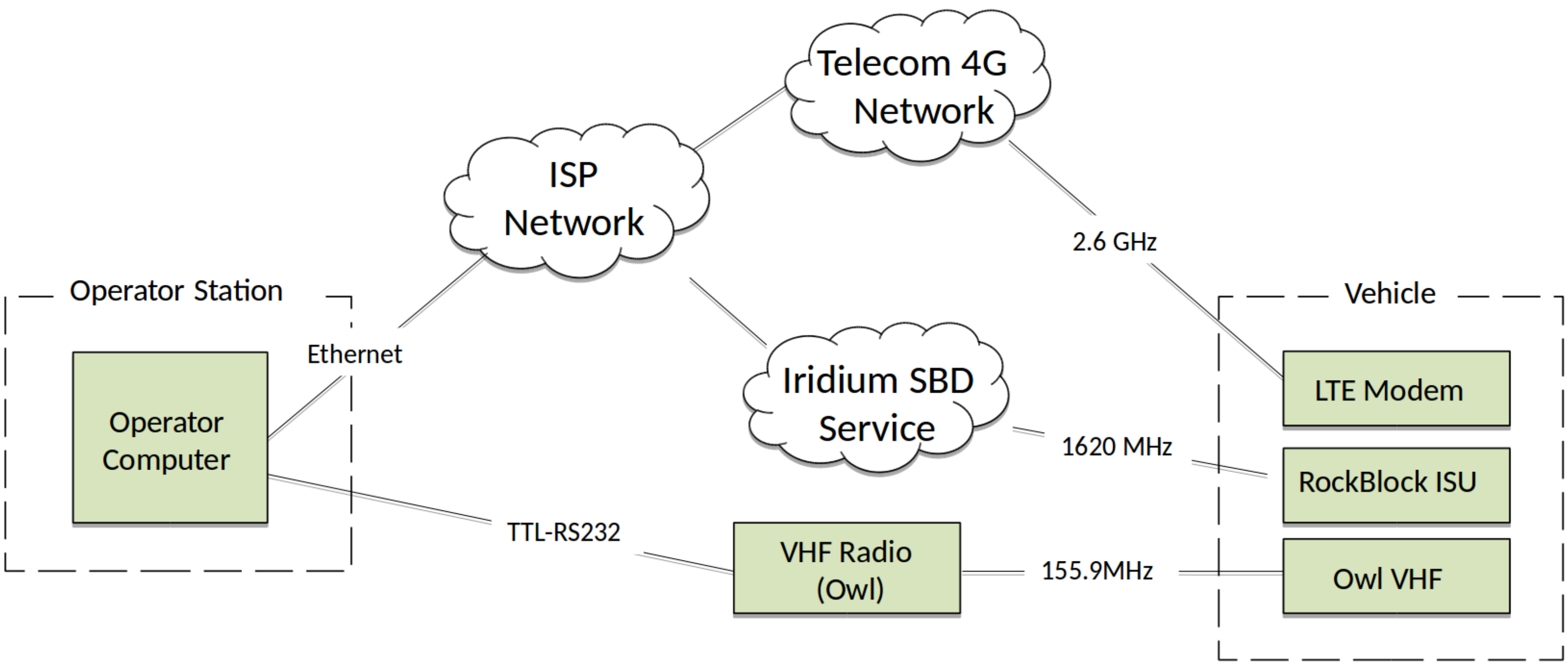

Fig. 9: Communication channels: 4G/LTE, VHF radio, Iridium Satellite.

Field Missions in Trondheimsfjord

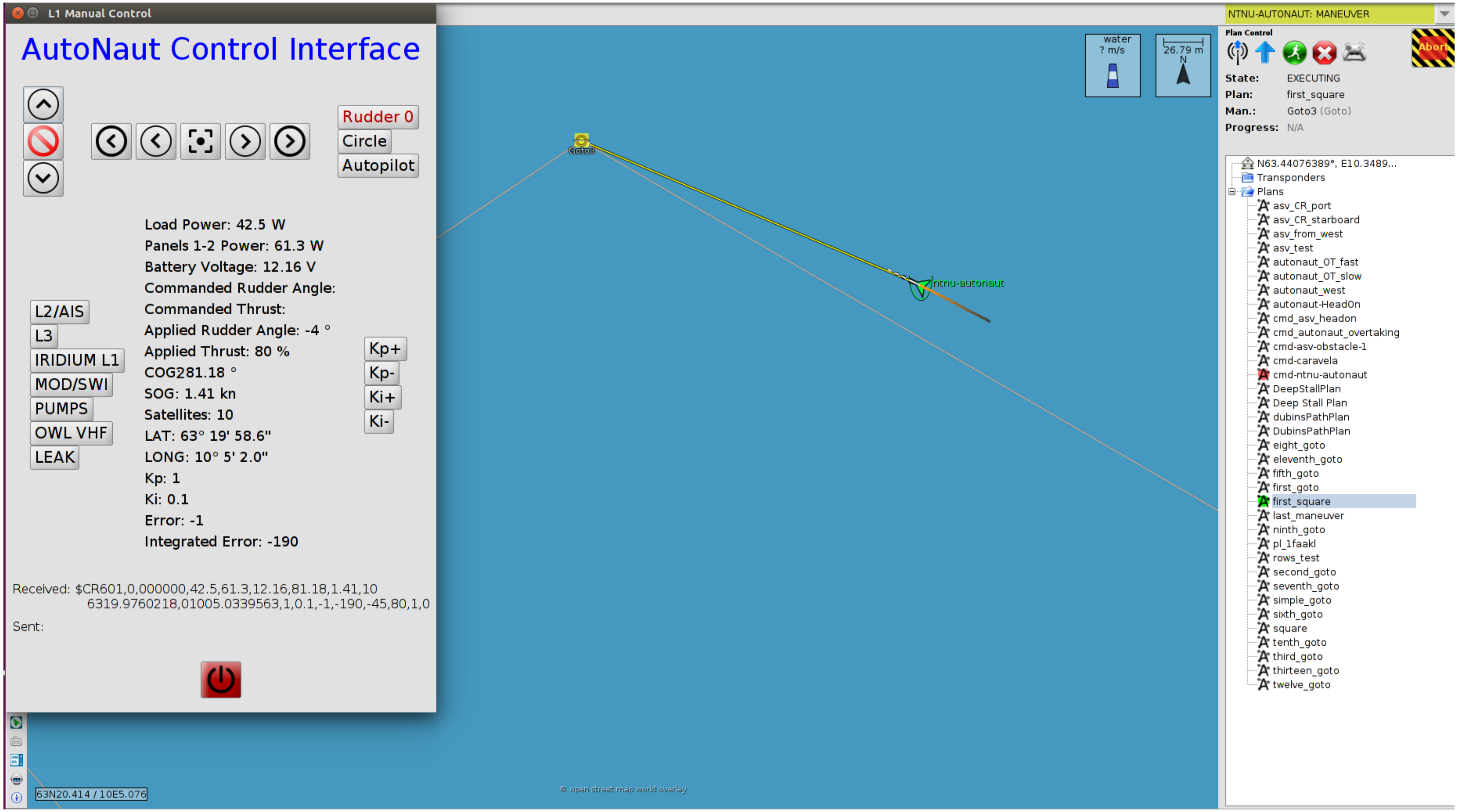

Fig. 10: LSTS Toolchain, user Interface for real-time monitoring of the mission [10].

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Preliminary Results

Fig. 11: 5 waypoints maneuver.

Fig. 12: Vehicle during a mission.

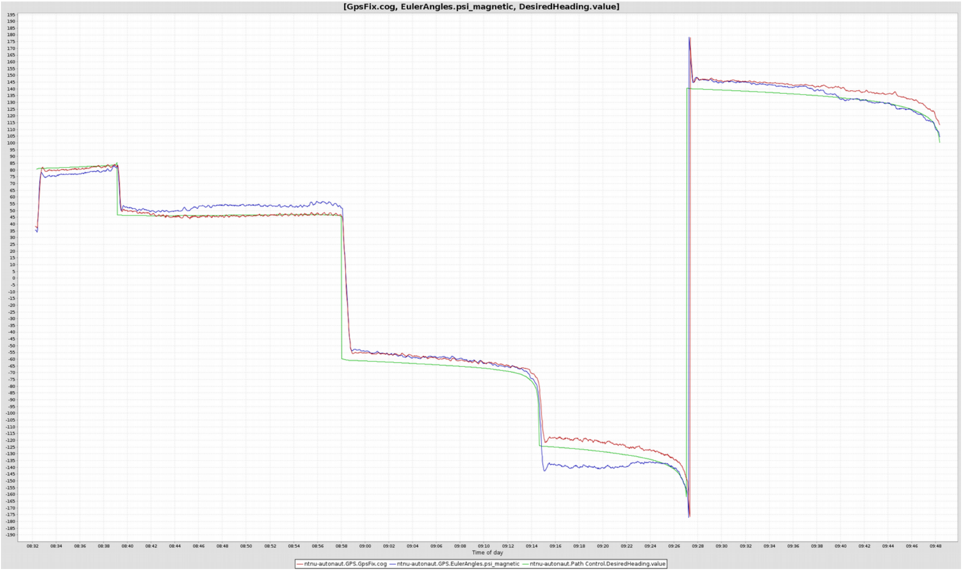

Fig. 13: Comparison between desired course, measured course and measured heading.

Main Challenges

- **Environmental factors**: propulsion depends on surface waves.
- **Balancing goal-driven opportunism with intent**: validity of collected data or water samples is highly time-dependent.
- **Onboard goal-driven autonomy has to trade operational risk**: onboard goal-driven autonomy has to combine *current* operational risk with the intent shaped by humans on shore.
- **Communication challenges**: what data transmit and when highly depends on the remoteness of areas of operation and therefore on the technology used.

Fig. 14: During operations.

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