

NATO CA2X2 FORUM 2026

TRACK – EXPERIMENTATION, EXERCISES & WARGAMING

GENERATING MDO READINESS THROUGH

STRESS-TESTED GOVERNANCE WARGAMING

WinterStorm2045 (formerly WinterStorm2030) and the Auracelle Simulation Suite

ASYNCHRONOUSQUANTITATIVEMULTI-STAKEHOLDER

GRACE-ALICE EVANS

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NATO STOTechnical Team Member, SAS-219 / SAC STC — since 6 Mar 2026

RESEARCHPhD Researcher, Bath School of Design, Bath Spa University

FELLOWSHIPNon-Resident Senior Fellow, UC Berkeley CLTC

Patent Pending · App. 19/768,839 · filed 7 Aug 2026

THE PROBLEM

THE READINESS GAP

Operational wargaming is well established. **Governance readiness** — the ability to rehearse decisions under ambiguity and pressure — is rarely stress-tested before crisis.

OPERATIONAL READINESS

MATURE

Forces trained across domains

Exercises rehearsed repeatedly

Capability gaps identified early

Well-funded wargaming culture

GOVERNANCE READINESS

UNTESTED

Legal authorities untested

Coalition alignment unrehearsed

Escalation thresholds unclear

Rarely stress-tested pre-crisis

WHY IT MATTERS

HYBRID THREATS UNFOLD BELOW THE THRESHOLD OF ARMED CONFLICT

ATTRIBUTION IS CONTESTED

Actors and intent are difficult to prove in real time

LEGAL AUTHORITIES ARE UNCERTAIN

Article 4/5 triggers and mandates remain ambiguous

COALITION INCENTIVES DIVERGE

Member-state interests are not uniformly aligned

DECISION TEMPO COMPRESSES

Crisis timelines outpace deliberative process

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CONTESTED DOMAINS

Arctic High North

Space Domain

Cyber Infrastructure

Information Environment

Nuclear / Renewable Energy

Quantum

5G / 6G

Biotechnology

THE INSTRUMENT

WINTERSTORM2045

A live, multi-stakeholder governance wargaming instrument built to stress-test institutional readiness against Arctic hybrid threats. Deployed as **Arctic High North Live Theatre v18**, in alignment with NATO STO SAS-219 High North scenario work.

MULTI-STAKEHOLDER

ASYNCHRONOUS

ARCTIC HIGH NORTH

LIVE / REAL-TIME

AI-ENABLED

MULTI-AGENT

NOAA-FED

ASYNCHRONOUS BY DESIGN

Players hand sessions off via Export / Import Turn files carrying full session state — scenario, logs, Cap Gap, doctrine. Own device, own time, no live connection.

IN PROGRESS

Sessions already export structured doctrine and move data. The Lab Environment's MARL calibration engine — refining Red Team doctrine weights across sessions — is under active development.

SUITE POSITION

One instrument in the Auracelle Simulation Suite — the same architecture family spanning cyber, space, nuclear and energy governance domains.

WARGAMING, ASYNCHRONOUSLY

Institutionalizing Continuous Decision Learning

BLUF

Asynchronous wargaming extends wargaming from an event into a continuous decision-learning capability.

INDIVIDUAL DECISION-MAKER

THINK. DECIDE. SUBMIT.

WHY IT MATTERS

- Build decision-making repetitions
- Expand who can participate
- Give players time to think
- Capture the decision trail

DISTRIBUTED TEAM CELL

COLLABORATE. ANALYZE. RESPOND.

COMPETITIVE ENVIRONMENTS

- Human ↔ Human
- Team ↔ Team
- Human ↔ Agentic AI
- Human + AI ↔ Human + AI

ADAPTIVE OPPONENT (AI)

- MODELS INTENT
- ADAPTS STRATEGY
- GENERATES RESPONSES
- CHALLENGES ASSUMPTIONS ?

OODA IN PRACTICE

Observe → Orient → Decide → Act → Receive Response → Reorient

ADAPT

THINK → LEARN → FAIL → ADAPT

The advantage goes to the force that learns and adapts faster.

WARGAMING THE GOVERNANCE, ASYNCHRONOUSLY

THE OPERATING CONCEPT

WARGAMING, ASYNCHRONOUSLY

Asynchronous wargaming extends wargaming from an *event* into a continuous decision-learning capability.

WHY IT MATTERS

- Build decision-making repetitions
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HOW IT PLAYS

THE CONTESTED NEGOTIATION TABLE

Participants respond to grey-zone shocks, negotiate resource access and sovereignty claims, assess escalation risk, and stress-test whether coalition governance holds under pressure.

LEGAL Tests legal authorities and Article 4/5 thresholds	MILITARY Assesses escalation risk and operational options	CIVIL SOCIETY Represents public legitimacy and local stakeholder interests	DIPLOMATIC Negotiates concessions and coalition alignment
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PLAY MODES

WHAT IT STRESS-TESTS

Arctic Governance

Hybrid Warfare

Diplomatic Negotiation

Article 4/5 Escalation Ladder

Concession Dynamics

Sovereignty & Resource Claims

Live Environmental Intelligence

HUMAN VS AGENTIC AI
Blue plays live; the AI Red Team generates its move each turn under its active doctrine.

HUMAN VS HUMAN SYNCHRONOUS
Same device, live turn-trading between Blue and Red players.

HUMAN VS HUMAN ASYNCHRONOUS
Different devices, any time — hand off via Export / Import Turn files.

THE FRAMEWORK

E-IAIG-HT

Enhanced Intent – Autonomy – Interaction – Governance — Hierarchical Theory. The **sole** governing framework, not a supplementary layer.

THE FOUR STRATA

GOVERNANCE

Coalition rules and legitimizing authority

INTERACTION

Negotiation moves between stakeholders

AUTONOMY

Degree of independent agent decision-making

INTENT

Underlying strategic objective of each actor

Powers actor scoring, inject calibration, Bayesian/Kalman tracking, and Governance Lab document analysis.

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HOW THE SCORE IS BUILT

1 Granular Indicators

Dozens of fine-grained institutional and environmental signals feed the model in real time

2 Institutional Domain Scores

Governance capacity across institutional domains, adjusted for AI-driven acceleration effects

3 Composite Readiness Score

Domain scores aggregate into a single 0–100 governance readiness index per actor

4 Environmental Modulation **NEW**

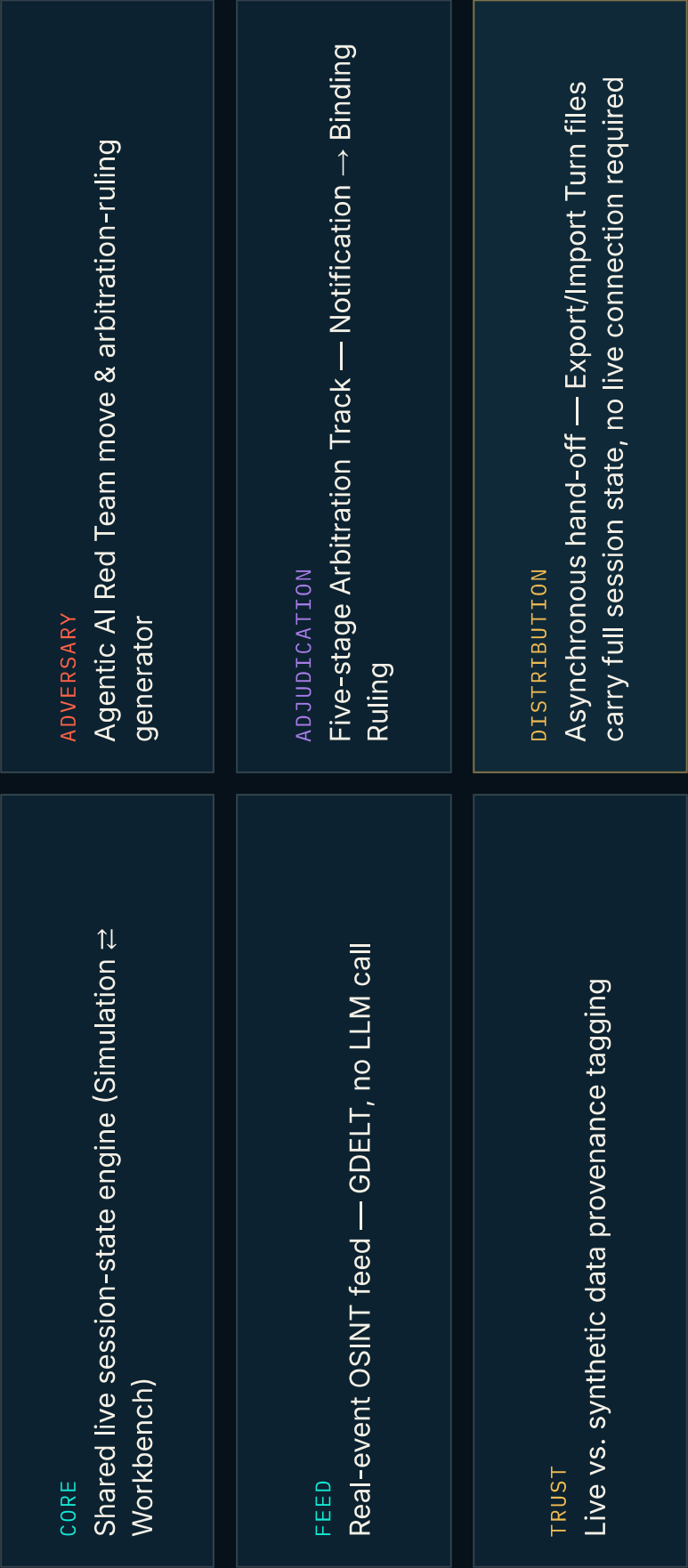
A cross-cutting layer adjusts the composite for real-world physical Arctic conditions before any scenario begins

Full mathematical specification is proprietary and patent-pending (US App. 19/768,839) — available to SAS-219 panel members under the working paper.

UNDER THE HOOD

TECHNICAL ARCHITECTURE — V18

Arctic High North Live Theatre



AGENTIC AI RED TEAM

MODELED ADVERSARY DOCTRINES

Each doctrine drives a distinct move pattern — calibrated as an analyst baseline, **not derived from incident data**, and open to revision under SAS-219 / SAC STC panel review.

RUSSIA

NARRATIVE-FIRST

Reflexive control, below-threshold probing, deniable escalation — e.g. unattributed vessel loitering near the GIUK corridor, paired with a compliance-doubt narrative push.

CHINA

PLATFORM-FIRST

Dual-use infrastructure, data leverage, long-horizon economic access — commercial and infrastructure footholds (NSR shipping, port and cable investment) carrying latent strategic value.

HYBRID

COMPOUND

Not tied to a single actor — deliberately calibrated to skew escalatory by design (“attention-saturation intent”), for scenarios stress-testing compound, multi-vector pressure.

SEPARATELY – THE CONTESTED TABLE IS NOT AN AI DOCTRINE

A negotiation mechanism that activates for any actor when a capability-gap threshold breaches with no movement for 3+ turns. The United States is Blue-aligned, not a Red doctrine — but its friction points (Greenland critical-minerals interest, basing posture) are a recurring Contested Table trigger.

NEW IN V18 ENVIRONMENTAL LAYER

LIVE ENVIRONMENTAL INTELLIGENCE

The Arctic operating environment feeds the simulation directly — **not as a backdrop, but as a live input to governance capacity itself.**

ENVIRONMENTAL INTELLIGENCE (EI) — LIVE NOAA/NWS

Temperature anomaly

NWS station PABR (Utqiagvik/Barrow, AK) vs. monthly Arctic norm

Sea-level reading

NOAA CO-OPS station 9468756 (Nome, AK), MLLW datum

Two builds, one flag

NOAA_FEED_ENABLED — standalone is always synthetic and offline-safe; live attempts the fetch and falls back identically on failure.

STRATUM IV — EOC SUB-DOMAINS PANEL-CALIBRATED, SET SEPARATELY FOR 2030 AND 2045

ACOUSTIC / SEABED

Siltation, ocean-column turbidity, basin anoxia — degrades passive sonar/ISR detection

SOLAR / EM INTERFERENCE

Solar-cycle ionospheric noise degrading GNSS/PNT precision

CRYOSPHERIC ACCESS

Sea-ice extent/timing shift; differential permafrost thaw stress

METEOROLOGICAL

Storm surge, sea-state instability, polar-vortex disruption

Combined factor (EOC × **live/synthetic EI**) feeds the Cap Gap, the Escalation Ladder, the Concession Engine, and the Quantum Optimizer.

QUANTITATIVE OUTPUTS

LIVE, CONTINUOUSLY-UPDATING SCORING

Quantitative scoring itself isn't new — RAND's Cold War games and methods like STAMPER used numeric scoring for decades. What's less common: a single composite score that updates live after every move, against formally specified escalation-zone thresholds.

ACTOR	TECH	DEF	INFRA	DEC	RISK	INFO	AUTO	COG	SCORE
Norway	78	82	75	80	77	73	65	61	74.8
Finland	80	78	72	82	79	76	68	64	75.6
Sweden	79	75	71	78	76	74	64	60	73.0
Denmark / Greenland	74	72	68	75	71	70	58	55	68.7
Iceland	65	60	58	67	63	42	56	38	59.3
Russia (Adversarial)	72	85	80	76	81	88	74	82	80.2

Eight illustrative institutional domains, unmodulated by environmental conditions — starting calibrations pending SAS-219 panel review.

LIVE CAPABILITY GAP

A single tracked number (0–100%) — the deficit between allied governance capacity and what the threat requires — moves after every move.

Win-Win: Cap Gap < 45% + a logged treaty concession

ESCALATION LADDER

$$\text{EscalationScore} = \text{Tension} \times 0.45 + \text{CapGap} \times 0.25 + \text{EscalateBonus} + \text{EnvPts}$$

< 40

Below Art. 4

40–69

Article 4 Zone

70–89

Article 5 Threshold

≥ 90

Past Art. 5 — tripwire

ARCTIC ECONOMICS

ECONOMIC VIABILITY OF ARCTIC ACCESS

A route can be environmentally navigable and institutionally uncontested — and still commercially non-viable.

That gap is itself a grey-zone signal: state-backed or sanctions-motivated actors tolerate uneconomic operations a market operator cannot.

ICE-CLASS VESSEL PREMIUM

20–30% above a conventional hull; suitable vessels in short supply

INSURANCE PREMIUMS

~400–900% above Suez transit; ~40% above the Cape of Good Hope route

RUSSIAN ICEBREAKER-ESCORT FEES

Mandatory for most vessels; ~\$470/container cited, variable by season — a lever Russia can adjust unilaterally

GROUNDING IN VERIFIED 2026 REPORTING

Sea Legend's China–Europe NSR container service; South Korea's Panstar Busan–Rotterdam trial; Japan's cautious engagement — cross-checked across trade press, The Arctic Institute and INSS.

SCOPE TODAY – QUALITATIVE, NOT YET SCORED

Drives scenario narrative and a new Japan / South Korea “Commercial-Observer” actor category. It does not yet feed the composite score, Cap Gap or Escalation Ladder. A scored version is flagged as future work.

INTELLIGENCE CORE UPDATE

QUANTUM-ENHANCED GOVERNANCE OPTIMIZATION

Closing the governance capacity gap is a combinatorial search problem — classical heuristics get trapped in local optima as the actor set grows.

9 × 3

actors × concession types

216

decision variables

≈ 10⁶⁵

possible concession portfolios



Quantum Amplitude Estimation — state projection

Variational quantum circuits — arbitration Nash equilibria

Quantum-enhanced sampling — Red Team move diversity

The composite readiness score is now environmentally modulated — that factor feeds directly into this same optimization. Patent pending, US App. 19/768,839 (filed 7 Aug 2026).

THE BROADER FAMILY

THE AURACELLE SIMULATION SUITE

Wargaming the Governance Asynchronously™ — each platform answers a different strategic question

WINTERSTORM2045	Will alliance governance hold under hybrid pressure?
POLARIS	How resilient is governance in contested space?
LYRA	Will safeguards and legal agreements withstand stress?
ORION	Where are governance and cyber resilience vulnerabilities?
STRESSPOINT	Which governance choices produce the greatest resilience?
DELPHI	Which cognitive futures should institutions prepare for?

SPACE-DOMAIN EXTENSION

AURACELLE POLARIS

Stress-tests orbital resilience and dual-use satellite governance within a broader MDO readiness context.

Orbital resilience

Satellite communications dependencies

Dual-use satellite governance

ASAT policy

POSITIONING

HOW WINTERSTORM2045 DIFFERS

The NATO M&S ecosystem includes both computer-driven simulation tools and facilitator-led tabletop exercises — each uses AI differently, or not at all. WinterStorm2045 is built for a layer neither fully addresses.

TYPICAL M&S TOOLING Optimizes force posture, logistics and tactical engagement outcomes Environmental inputs are static parameters set before the exercise begins Outcomes are simulation-run results, not live negotiated concessions Adversary behavior is typically scripted or rule-based, fixed before the run	TABLETOP WARGAMING Facilitator-led and qualitative — outcomes judged by expert adjudication, not a computed score Synchronous, single-session — all participants together, fixed duration No live data feeds — environment and adversary moves scripted or improvised Adversary moves role-played by a human Red Team or the facilitator — no AI component	WINTERSTORM2045 Models the governance layer directly — legal authority, coalition alignment and escalation thresholds as the object of the exercise Live NOAA/NWS data feeds the simulation in real time; playable synchronously or asynchronously Live composite scoring throughout play, not only after-action judgment Agentic AI Red Team generates moves and arbitration rulings live under a modeled doctrine — or swap in a human Red Team In progress: MARL for the Lab Environment's calibration engine, refining doctrine weights across sessions
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VALIDATION STATUS & LIMITATIONS

VALIDATION STATUS & WHERE IT BREAKS

BUILT & OPERATING

Shared live session-state engine (Simulation $\rightleftharpoons$ Workbench)

Live NOAA/NWS feed with synthetic fallback + provenance tagging

GDELT real-event OSINT ingestion

E-IAIG-HT scoring engine and composite readiness score

SCHEDULED FOR VALIDATION

Full Arctic High North run — 9-actor, 216-variable case (Quantico Workshop)

Quantum optimizer benchmarked against classical baseline on live scenario data

Five-stage Arbitration Track exercised end-to-end, multi-stakeholder

Distributed execution by outside player organizations (2027–28)

ATTRIBUTION DATA

OSINT/GDELT feeds carry noise and reporting lag; the model does not resolve contested attribution, only represents it as an input.

AI-GENERATED MOVES

Red Team and arbitration outputs reflect model biases from training and prompting; rulings are advisory, not binding without human review.

QUANTUM LAYER MATURITY

Current QUBO/Ising formulation runs on a quantum simulator / cloud annealer; a classical fallback exists but changes solution quality at scale.

SINGLE-POINT DEPENDENCY

Founder-led development to date; institutional continuity depends on a named backup lead within SAS-219 / SAC STC.

CREDENTIALS & INSTITUTIONAL STANDING

VERIFIED STANDING BEHIND THE INSTRUMENT

USPTO — PATENT PENDING

Application No.
19/768,839

Filed 7 Aug 2026 — Utility,
Nonprovisional (35 USC 111(a))

"Systems and Methods for Quantum-Enhanced Governance Capacity Gap Optimization in E-IAIG-HT Computer-Implemented Wargaming Workflows and Platforms, and Instruments"

PHD RESEARCHER

Bath Spa
University

Bath School of Design — part-time,
remote. Enrolled March 2026.
Director of Studies: Dr. John Curry

"Testing Public Policy Outcomes through War Gaming Methodologies for Strengthening AI Governance Across Sectors"

NATO STO

Technical Team
Member, SAS-219

Appointed 6 Mar 2026 by John
Hamilton, National Coordinator (US),
NATO STO CSO. High North Scenarios
for Wargaming and Analysis —
Technical Role Member (R4, R5, R7).

Committee update (1 Jul 2026): activity
now under the SAC Scientific and
Technical Committee per STO's CPoW
restructuring — administrative renaming
only, technical objectives unchanged.

INSTITUTIONAL ALIGNMENT & ROADMAP

WHERE IT LANDS, AND WHEN

ALIGNMENT WITH SAS-219 / SAC STC DELIVERABLES

TECHNICAL REPORT
to STO — routes to the Chief Scientist Champion

NATO ARCTIC STRATEGY 2030
via the Military Committee to SHAPE / JFC Norfolk

IMPLEMENTATION PLAN
routes to CNAD

ARCTIC FUTURE OPERATING ENV. 2045
via the Military Committee to HQ SACT

ROADMAP

Aug 2026

QUANTICO WORKSHOP
Finalize wargame methods and mechanics

Status to confirm — date passed as of forum prep

Nov 2026

HELSINKI
Execute wargame methodology; present → 2045

Upcoming

2027–28

DISTRIBUTED EXECUTION
Outside player organizations run wargames, plus red team and augmentees

Planned

CLOSING

REHEARSE THE GOVERNANCE, NOT JUST THE WAR

WinterStorm2045 and the Auracelle Simulation Suite give NATO and allied institutions a way to stress-test governance decisions — **before crisis, not during it.**

Generating decision-support insights

Capturing governance failure modes

Identifying refinements to policy, agreements and coalition procedures

FORUM TRACK FIT

MDO readiness requires not only training forces to operate across domains, but rehearsing the governance mechanisms that **authorize, constrain, coordinate and legitimize** action across them.

GRACE-ALICE EVANS

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THANK YOU

WARGAMING THE GOVERNANCE, ASYNCHRONOUSLY