Decision Making in Uncertainty

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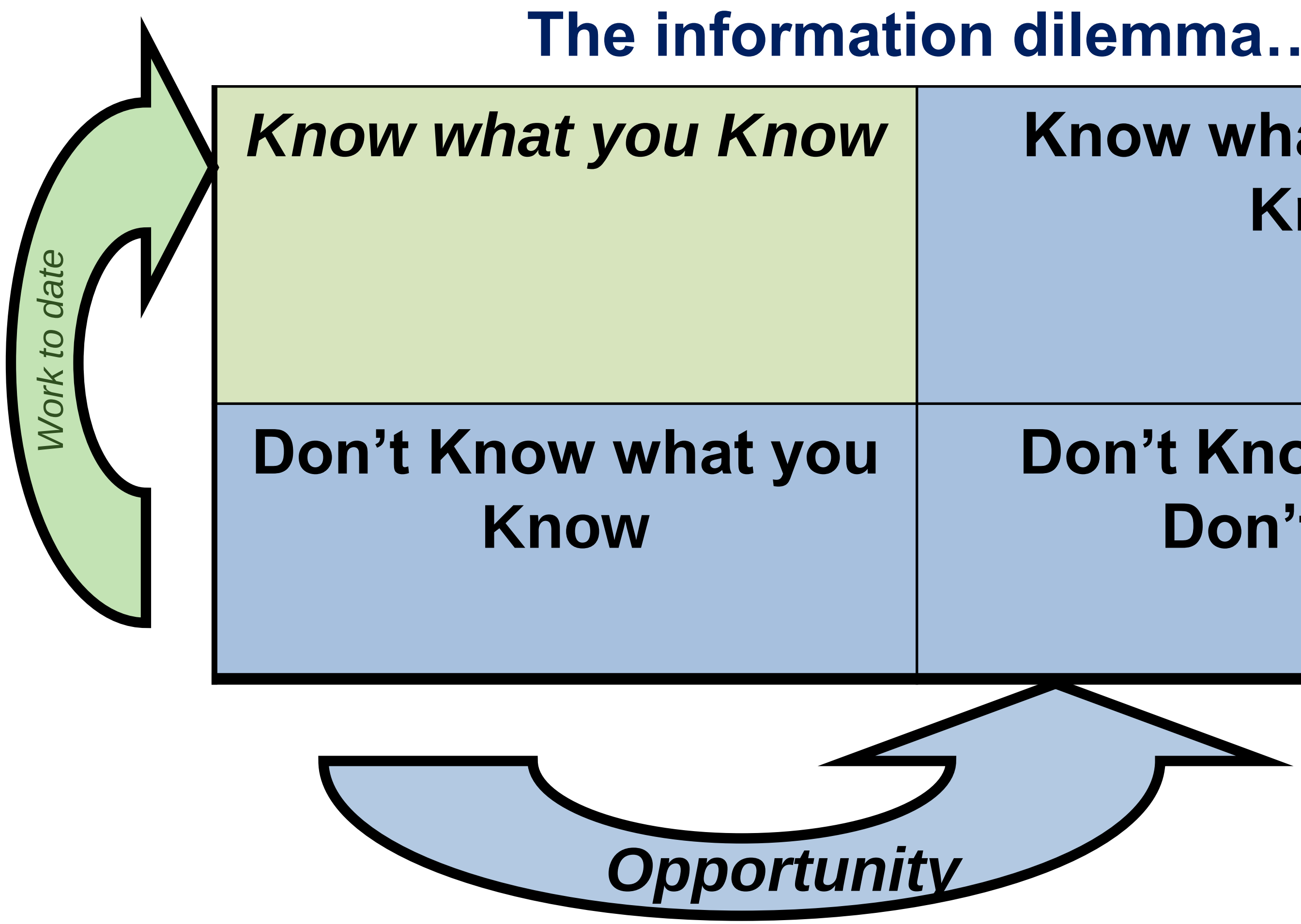
Jeffrey G. Morrison, Ph.D
Office of Naval Research
Arlington, VA
jeffrey.g.morrison@navy.mil

Research needed to address the information dilemma…



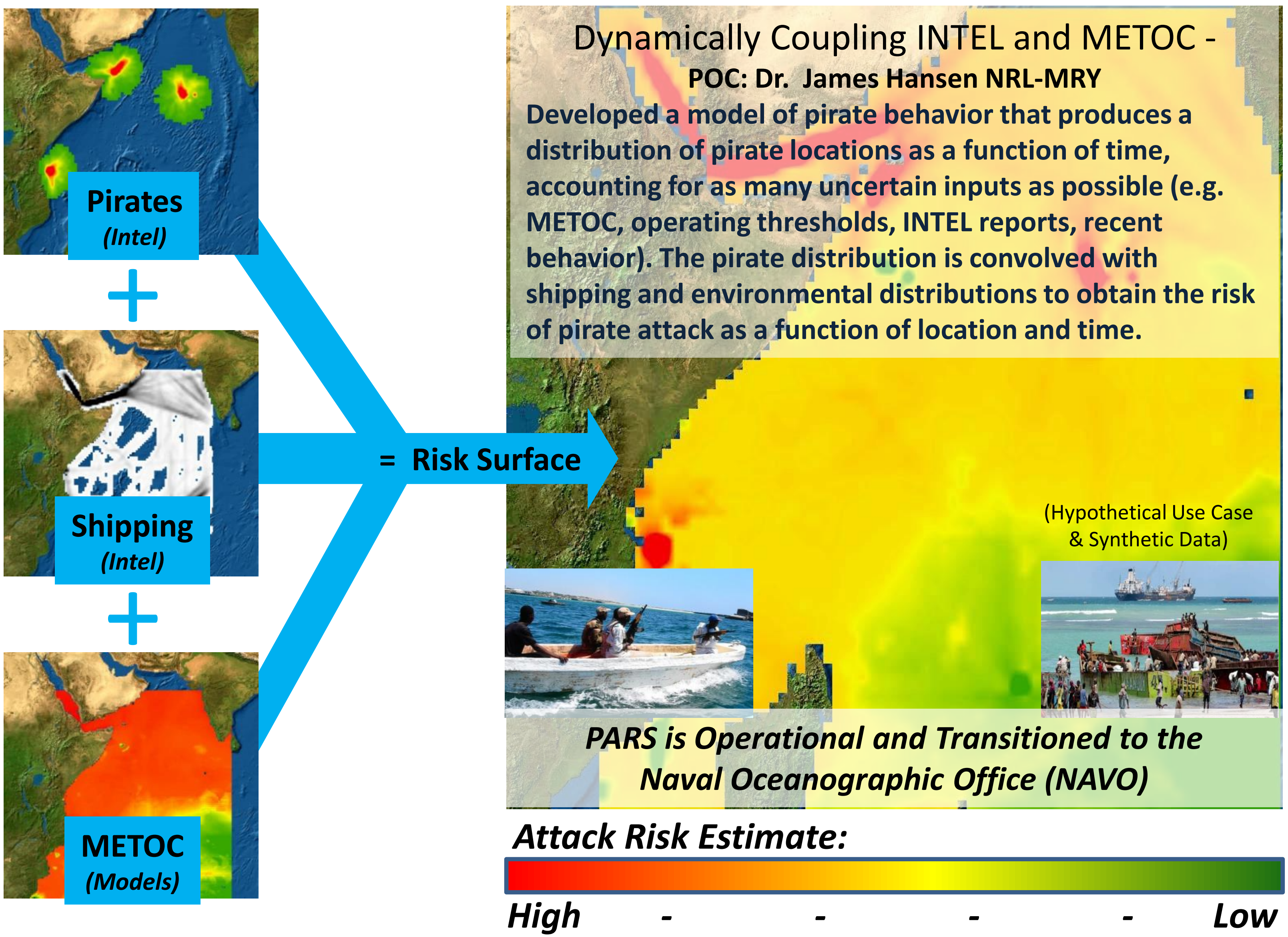
How can we help make Decisions in Uncertainty?

- **A notion…**
  - It would be helpful to ***Characterize Uncertainty…*** not just model it.
  - Need to: ***Develop tools to manage what you Know (& Don't Know…)***
    - Show how what you don't know is impacting your decision space
      What is most significant?
      What is worth worrying about?
    - Let the decision maker chose what uncertainties are most important / meaningful!
    - Use models to optimize given the decisions
    - *Rinse & Repeat…*

- **Consider Meteorology as a model for Decision Making in Uncertainty:**
  - ***Guidance*** ***(machine) vs.*** ***Forecasts*** ***(human)***

- **By way of example….**
  - *Piracy Prediction*
  - *Optimizing assets for countering smuggling*

Pirate Attack Risk Surface (PARS)



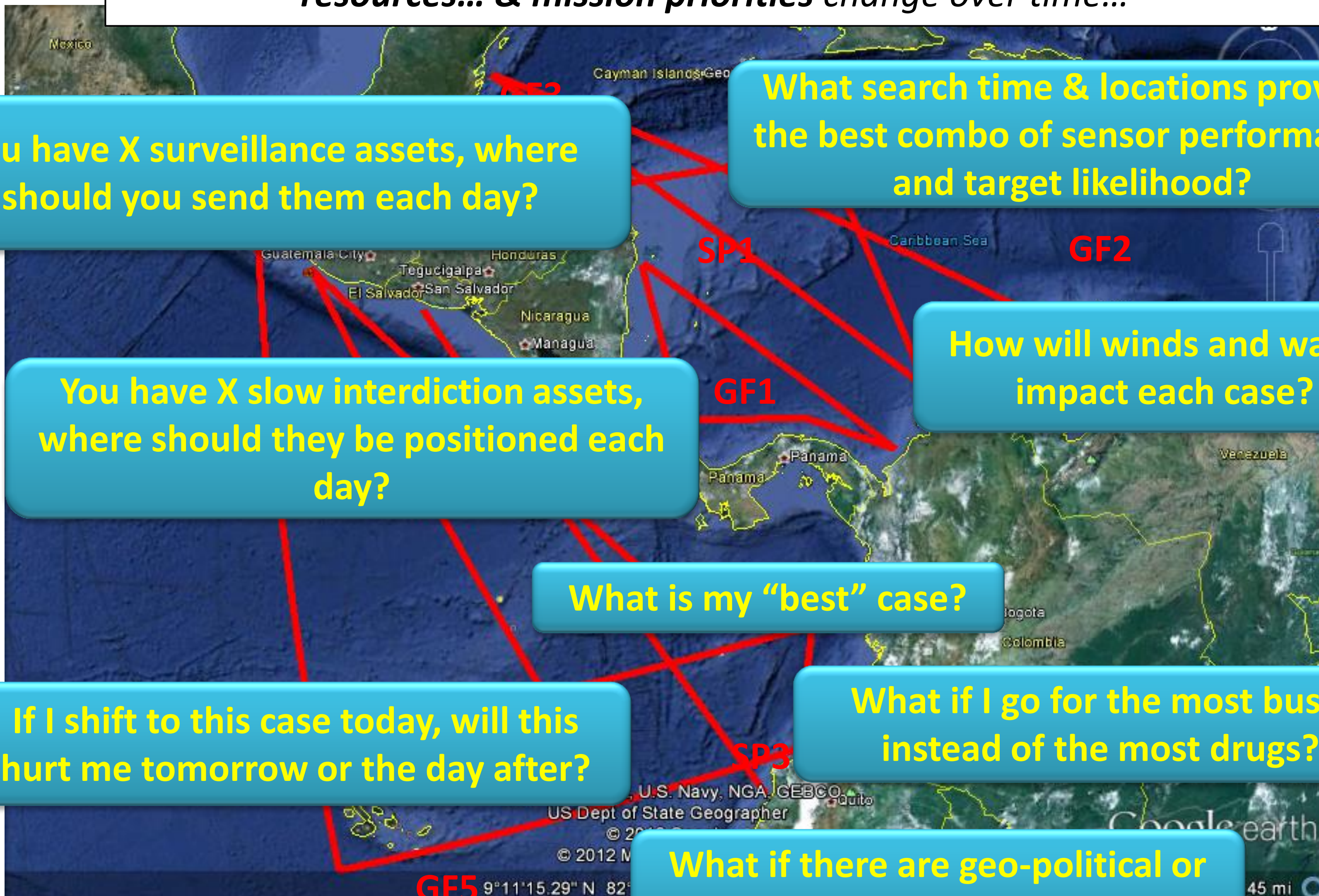
An Uncertainty Challenge…

- Many DOD mission areas need to **Maximize the Impact of Limited Operational Assets** allocated within a **dynamic and uncertain "targeting" environment**.
  - Need decision support to optimize *despite* uncertainties.
  - *We are using JIATF-S as a test-bed to develop a general approach.*
- **S&T community needs to Understand the role of Uncertainty** in the "targeting" process
  - How might we develop strategies for *Managing Uncertainty?*
  - Can we *Optimize* given the uncertainties?
- **Can we Develop Quantitative Decision Support to Manage Uncertainty?** for targeteers, planners, and watchstanders to determine when & how to re-task operational assets?

Manage Uncertainty to Maximize ROI of Limited Assets and Tighten the "Targeting Loop"

Counter Smuggling:
Where do you allocate your assets for the best ROI?

Cases overlap in time and space and so there are ***trade-offs for limited resources… & mission priorities*** *change over time…*



You have X surveillance assets, where should you send them each day?

What search time & locations provide the best combo of sensor performance and target likelihood?

How will winds and waves impact each case?

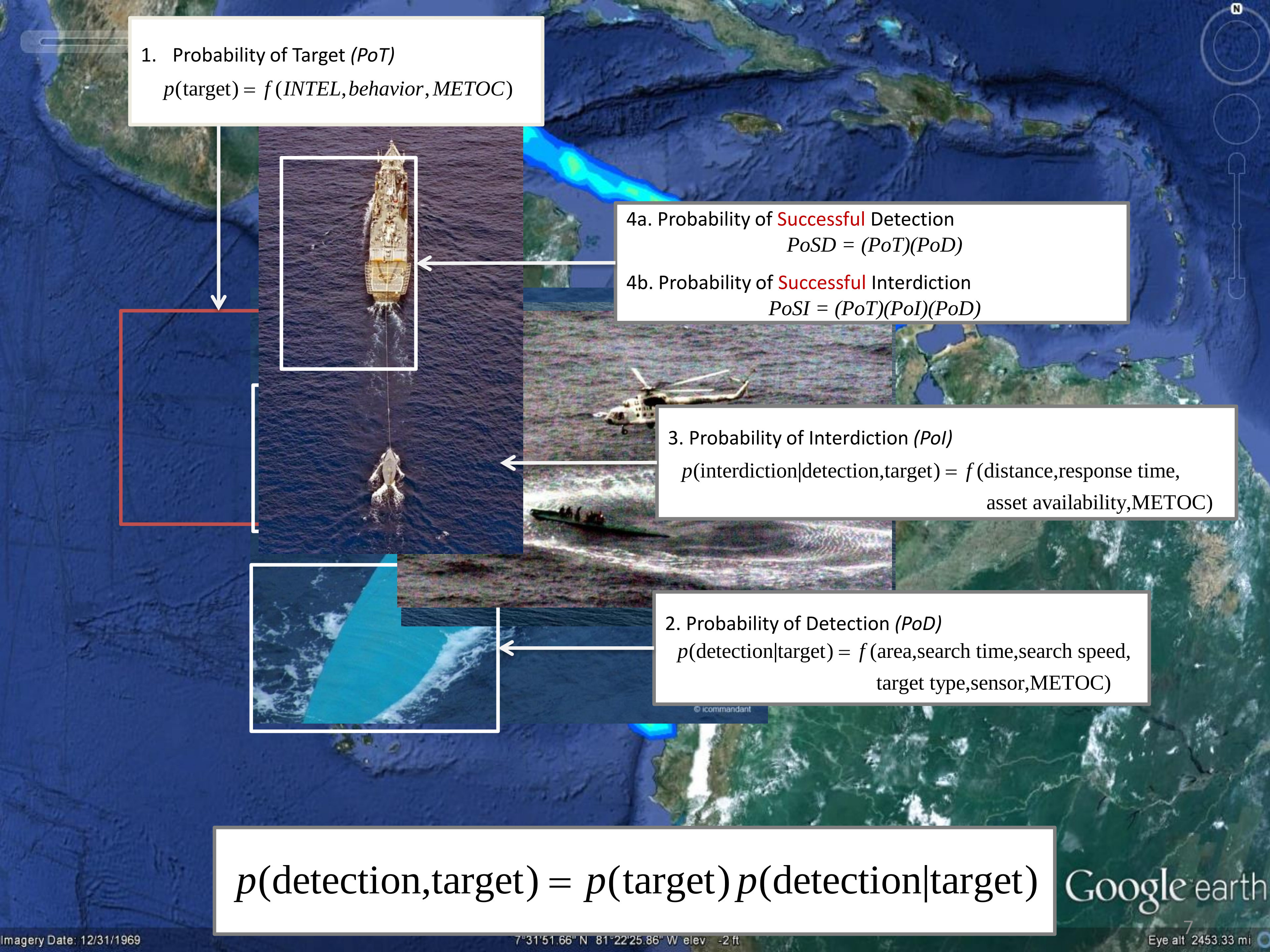
You have X slow interdiction assets, where should they be positioned each day?

What is my "best" case?

If I shift to this case today, will this hurt me tomorrow or the day after?

What if I go for the most busts instead of the most drugs?

What if there are geo-political or social-cultural considerations?


1. Probability of Target *(PoT)*
$p(\text{target}) = f(INTEL, behavior, METOC)$
4a. Probability of Successful Detection
$PoSD = (PoT)(PoD)$
4b. Probability of Successful Interdiction
$PoSI = (PoT)(PoI)(PoD)$
3. Probability of Interdiction *(PoI)*
$p(\text{interdiction}|\text{detection,target}) = f(\text{distance,response time, asset availability,METOC})$
2. Probability of Detection *(PoD)*
$p(\text{detection}|\text{target}) = f(\text{area,search time,search speed, target type,sensor,METOC})$
$p(\text{detection,target}) = p(\text{target})\, p(\text{detection}|\text{target})$
© icommandant
Google earth
Imagery Date: 12/31/1969
7°31'51.66" N 81°22'25.86" W elev -2 ft
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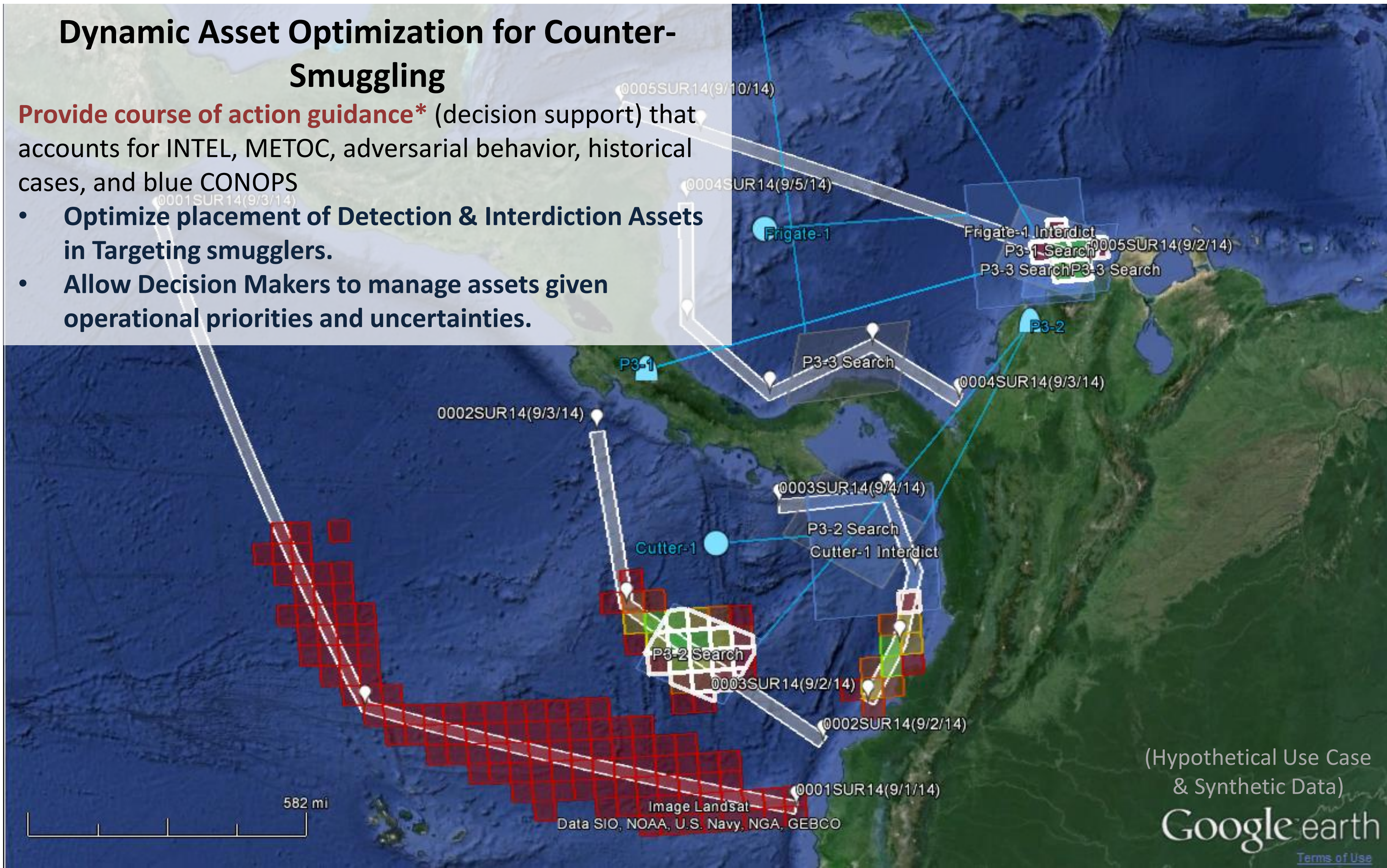
Targeting in Uncertainty (TiU)

Dynamic Asset Optimization for Counter-Smuggling

Provide course of action guidance* (decision support) that accounts for INTEL, METOC, adversarial behavior, historical cases, and blue CONOPS

- **Optimize placement of Detection & Interdiction Assets in Targeting smugglers.**
- **Allow Decision Makers to manage assets given operational priorities and uncertainties.**

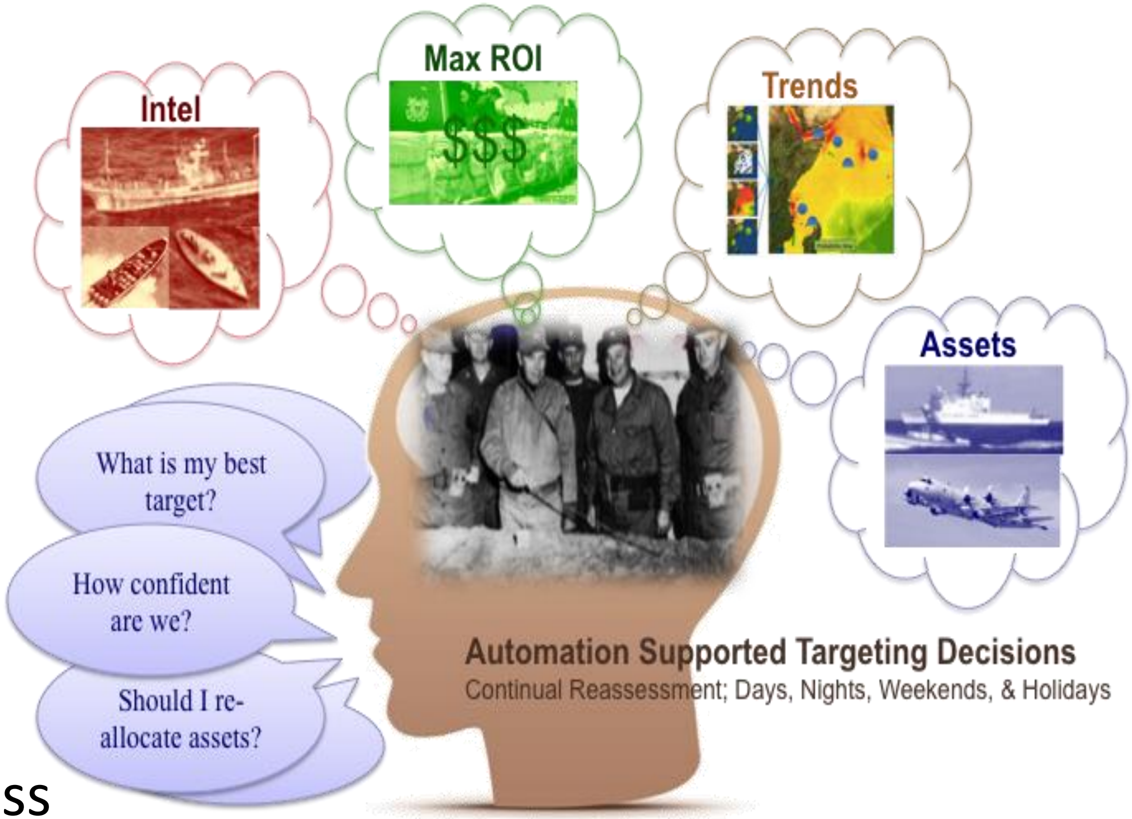


(Hypothetical Use Case & Synthetic Data)

Vision:

"24/7 Targeting Board" Decision Support System

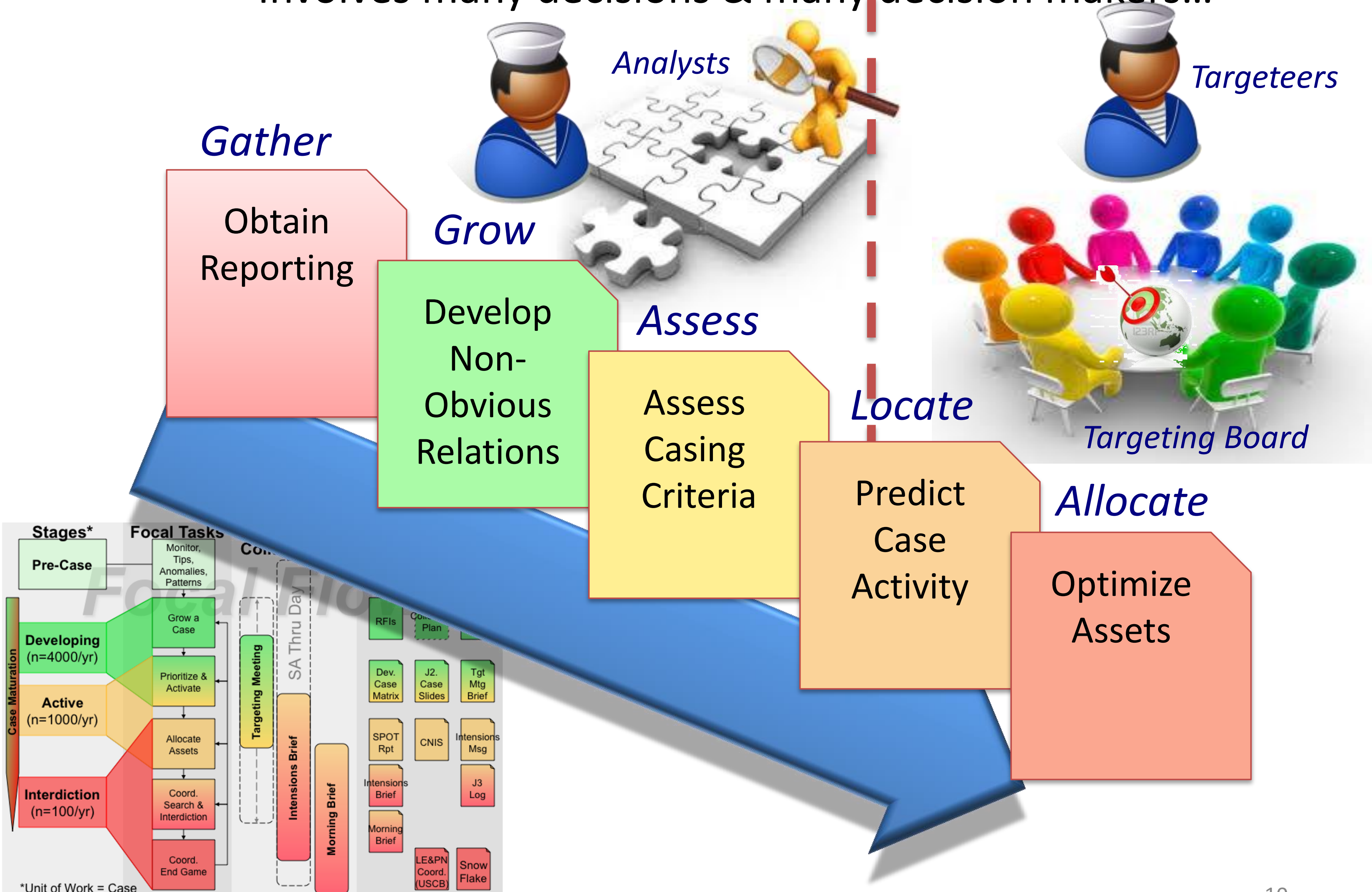
- Predict trafficking activity by understanding **Uncertainty & Flow**
- *Optimize targeting solutions based on alternate objectives* & user settings
- Evaluate manually entered solutions
- *Update with new intel*
- *Compare solutions* across time, space, and objectives



Persistent decision support for evaluating and recommending alternate targeting solutions within a limited asset, uncertain target domain.

"Targeting" is a process…

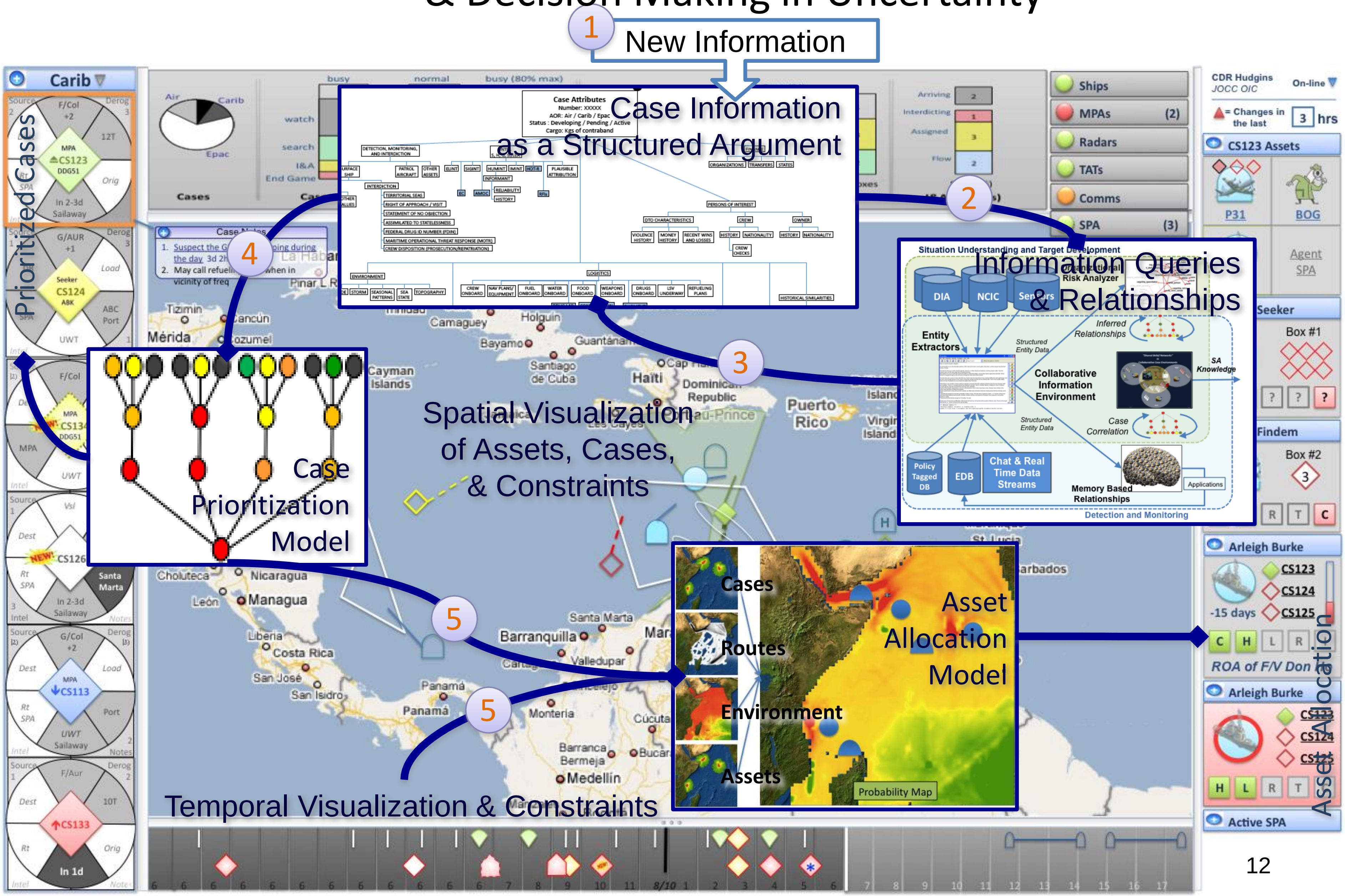
Involves many decisions & many decision makers…



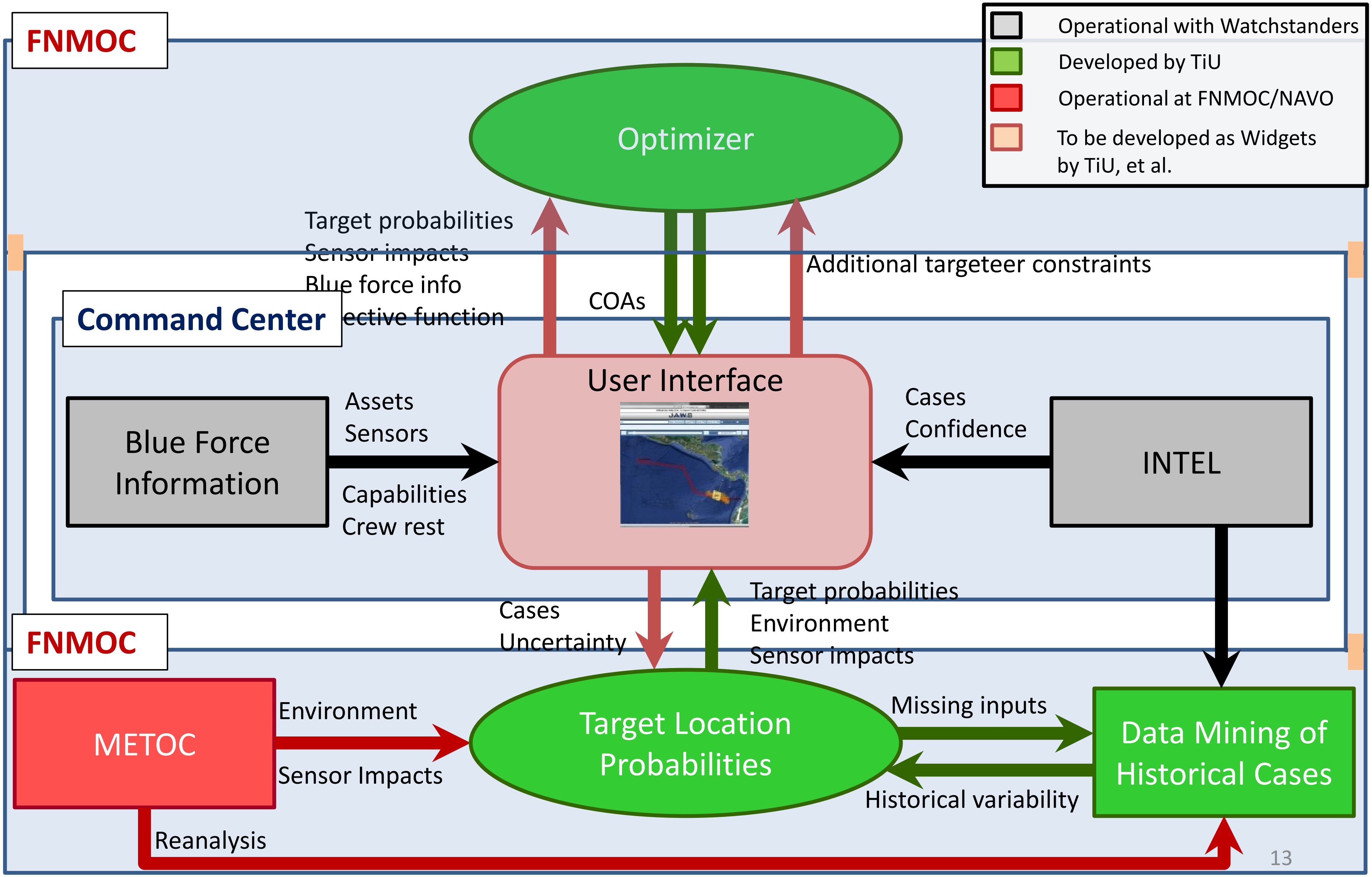
A notional "Targeting" Use-Case: *Decision Workflow…*

- Start with an asset list, capabilities, status, schedule, and laydown
- Prioritize existing developing, pending, and active cases
- Consume new case intelligence (TATs, Alphas, INTs, etc.)
- Grow additional case information by relating historical reporting (Derog). Analysts review and edit this analysis to assess case criteria.
- Nominate new pending and active cases, then re-prioritize cases.
- Recommend alternate search and interdiction asset allocations
- Show the predicted impact as users modify prioritizations and/or allocations. Allow the user to select/create their intentions.
- Generate an Intensions "Message" and "Brief" for (*some period of time*).
- During the (*period of time*), get new case intelligence
  - Alpha reports from MPA flights (STOIs)
  - TAT or other human reporting (New Cases, Case Updates)
  - Case updates (SIGINT, ELINT, Sailaway, SPA)
- *Consider re-allocation of assets….*

A notional "Dashboard" for Data Fusion & Decision Making in Uncertainty



TiU Decision Support Engine



Command Decision Making Program:

COAST (Courses of Action Simulation Tool)

Description: "Targeting in Uncertainty" Optimization models for dynamic asset allocation.

- **Overall FY14 Improvements**
  - Optimize across multiple active cases & Statistical "Flow" models
  - Dynamic updates with new information
  - Incorporate asset availability schedules
    - Dynamic coordination of both interdiction and surveillance assets
  - Enable user-specified COAs in optimizations with Multiple objective functions
    - Optimize for any number of days
    - Account for case priorities
  - Explaining allocation decisions

- **Surveillance Improvements**
  - New algorithm (Branch and Bound) implemented
    - Account for:
      - Cruise speed
      - On-station speed
      - Endurance
      - Rest requirements

  - Ability to specify surveillance operations for night or daytime
    - Surveillance patrol box minimum size of 125 x 250 km^2 (based on JIATF-S input)
    - For each asset, ability to specify:
      - Departure time (or windowed)
      - Target type to avoid/search for
      - Case to avoid/search for
      - Operating area

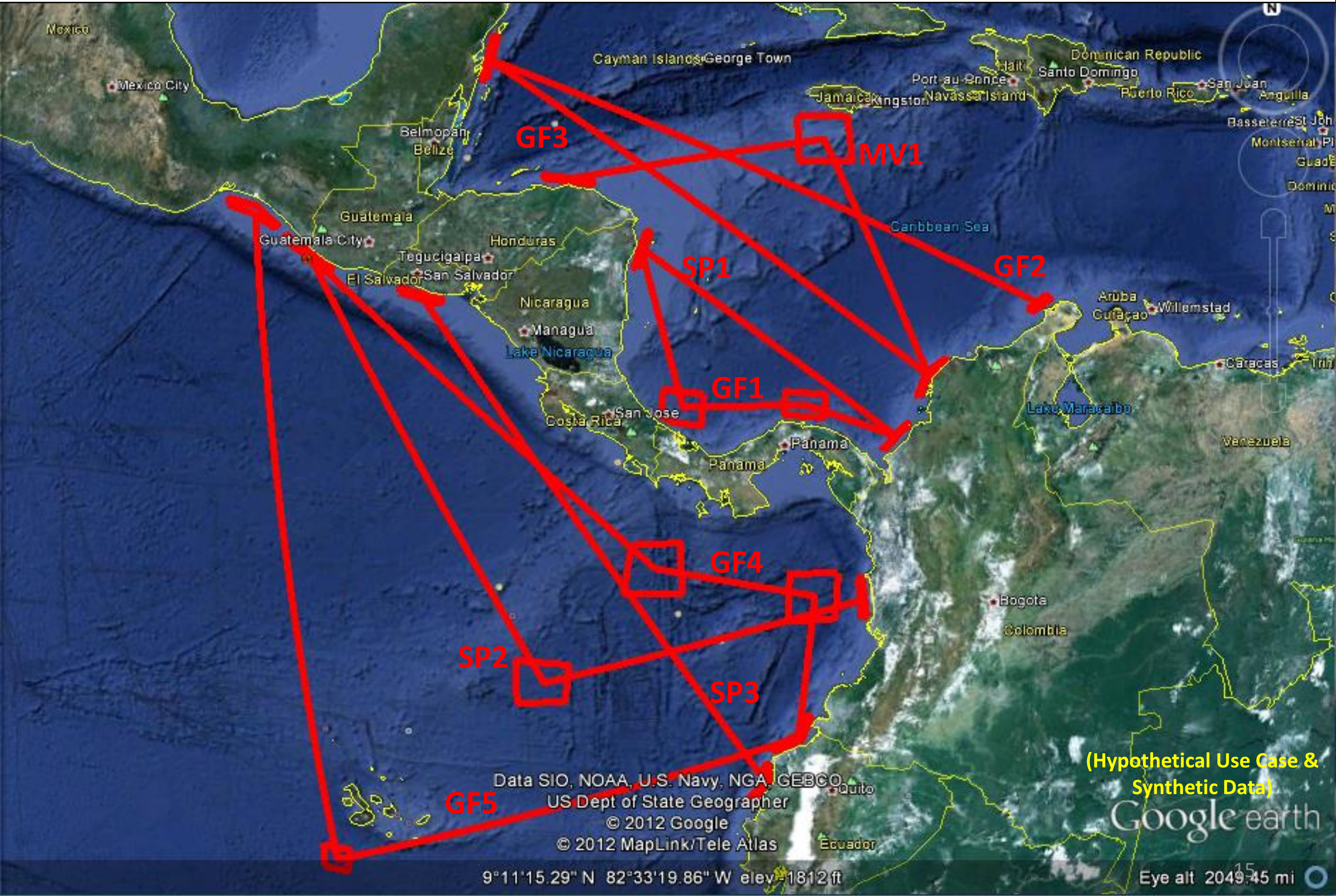
- **Integration**
  - Transitioned to SIPRNet and NIPRNet clusters at NRL-MRY and super computer cluster at FN-MOC
  - Full integration with JIATF-South Watchfloor databases

- **Interdiction Improvements**

  - Search space reduction
    - 2-fold reduction in solution time
  - Dynamic coordination with surveillance

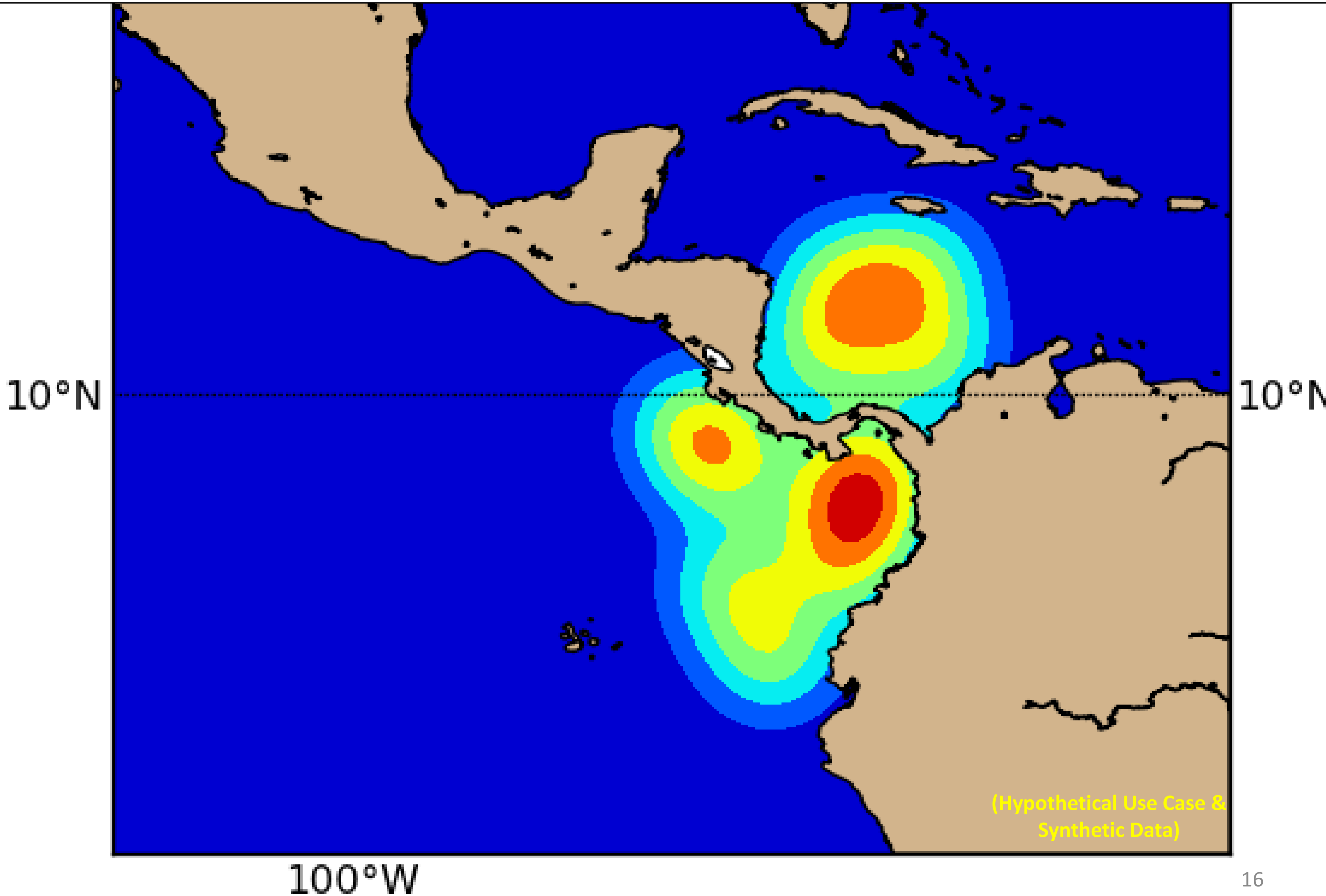
TiU enables targeteers to account for many types of uncertainty:

Departure & arrival locations, waypoints, speed, METOC impacts, overall confidence



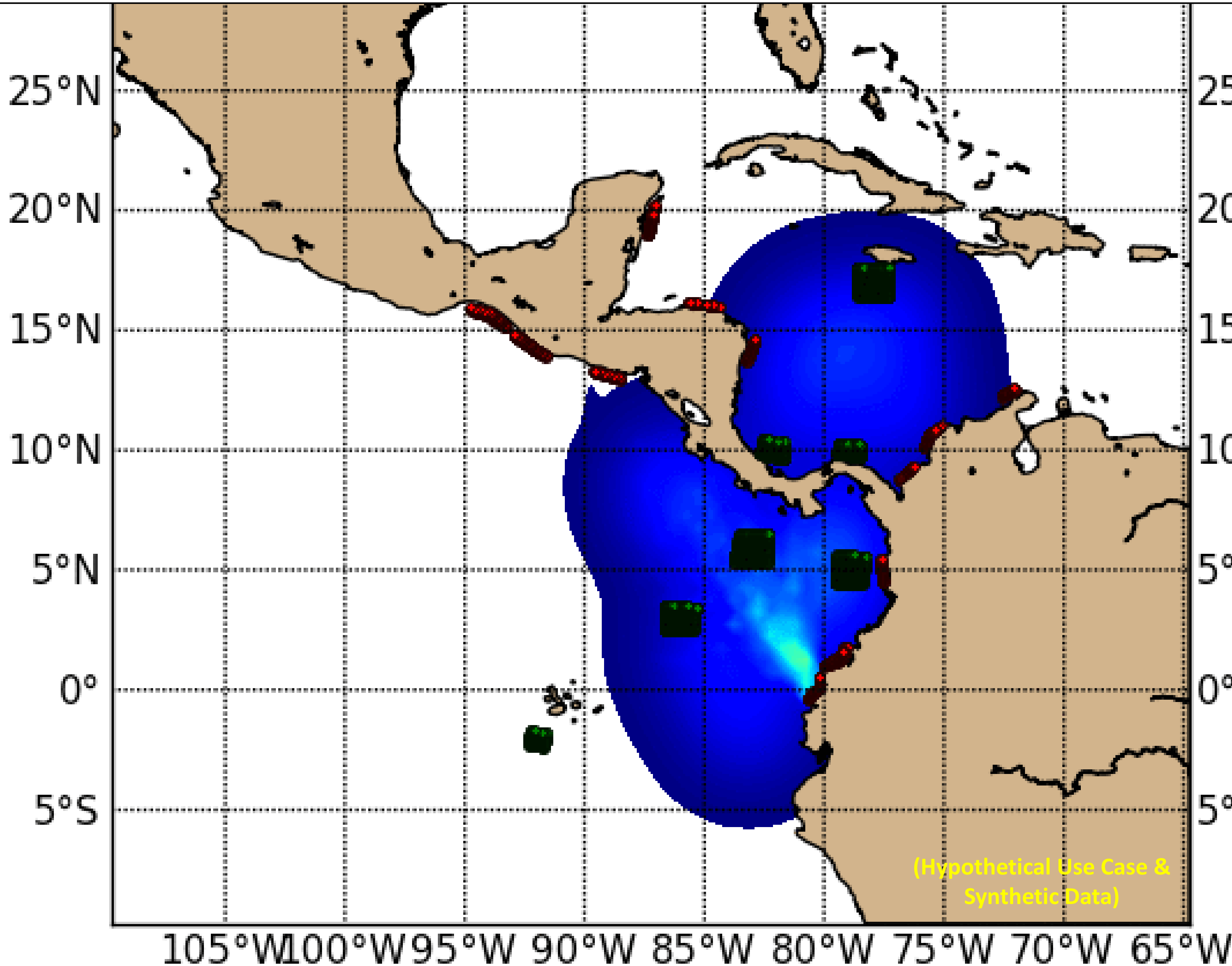
Must incorporate imperfect INTEL

E.g. $p(\text{target})$, obtained from conditionally mining historical cases



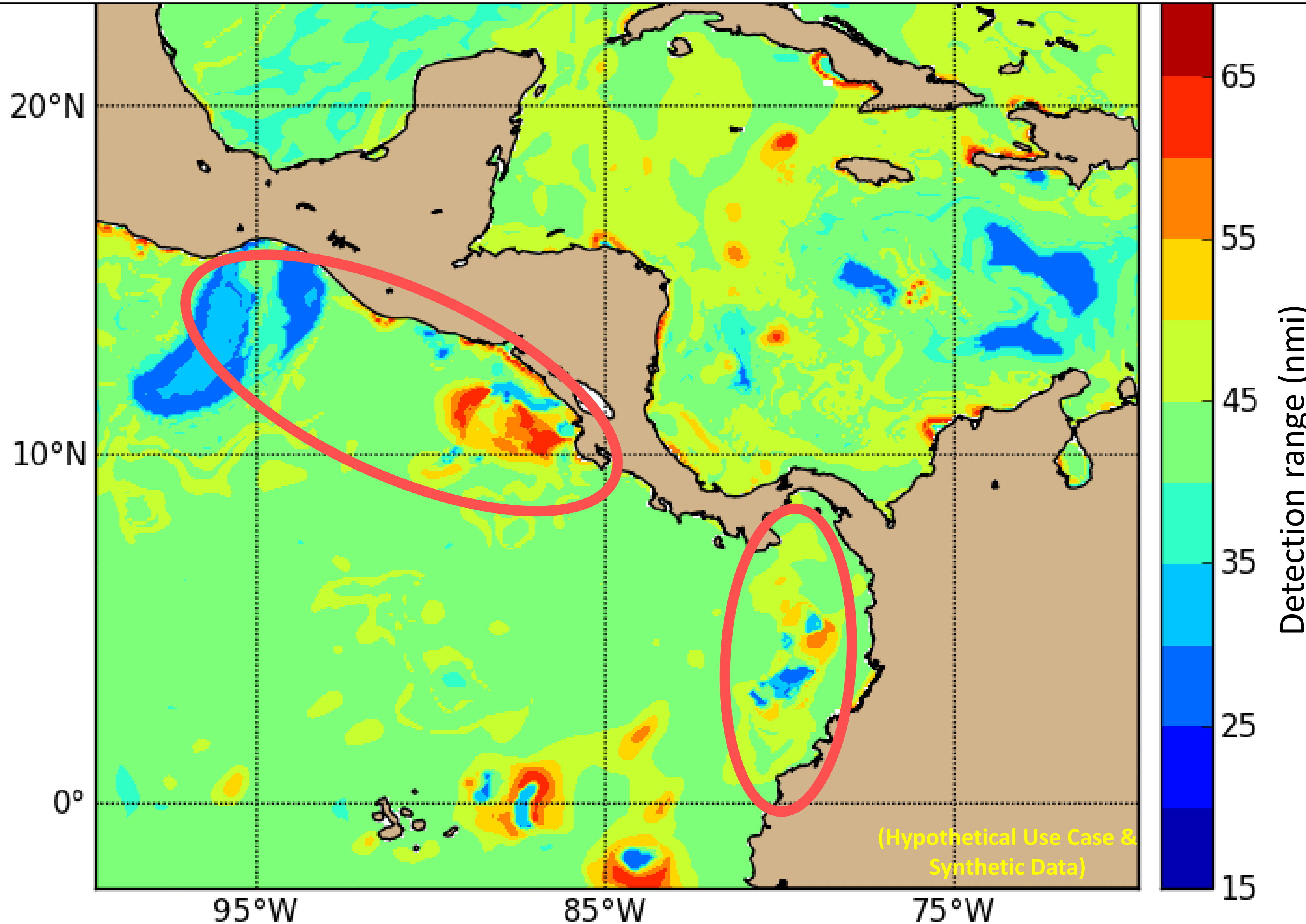
Evolution of all cases plus "flow"

Decisions should be made on the *combined information* from all cases



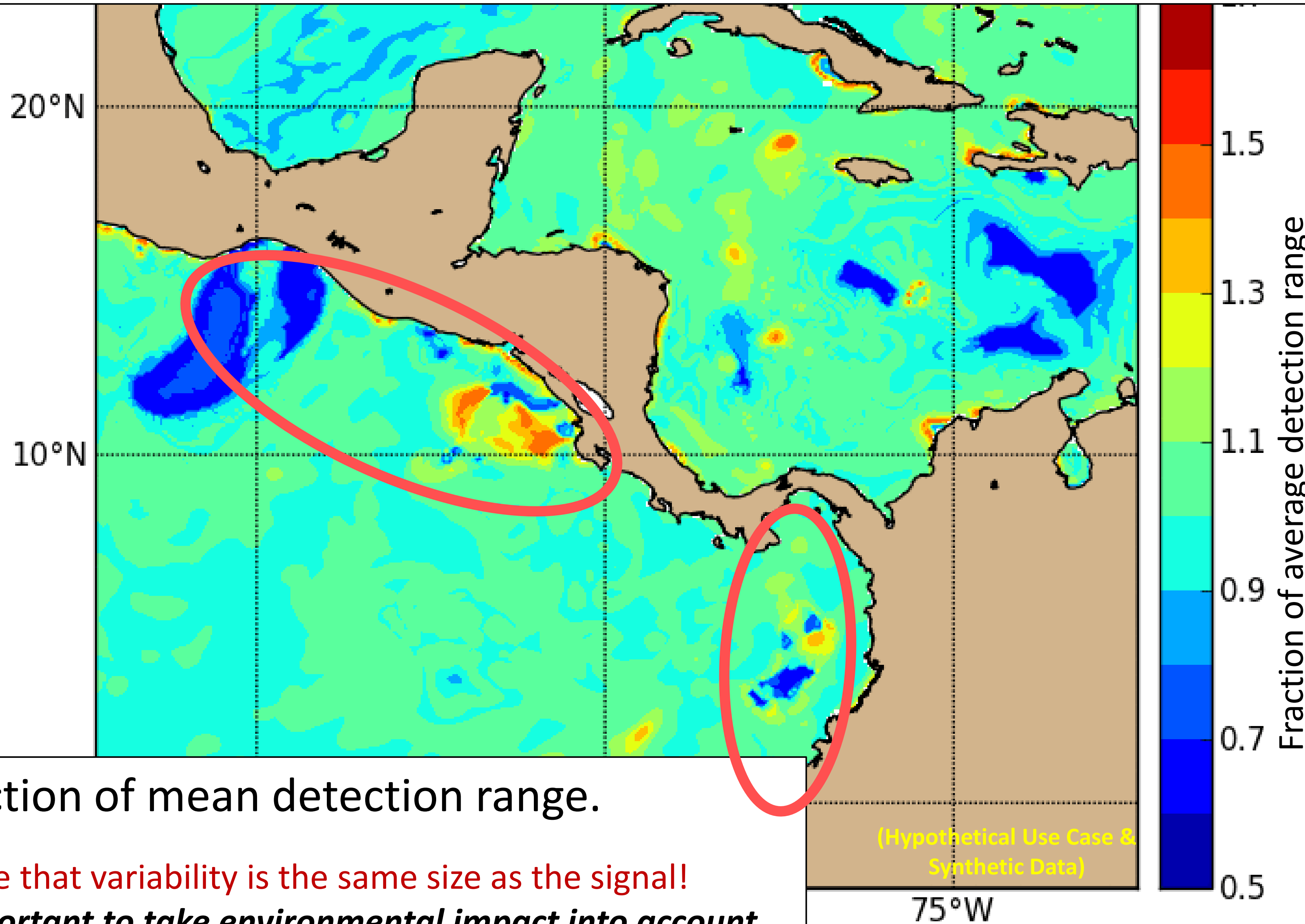
Radar detection ranges evolve in space and time, & f(METOC)

Detection ranges as a function of location for a P3 flying at 1000' looking for a small boat



Radar detection ranges evolve in space and time

Detection ranges for a P3 flying at 1000' looking for a small boat



Fraction of mean detection range.

- Note that variability is the same size as the signal!
- ***Important to take environmental impact into account.***

Notional Decision Making in Uncertainty Metrics

- Allow minimally trained watchstanders to make model-based, informed targeting and asset allocation decisions within 15 minutes (goal = 5 minutes) of receiving new intelligence or Alpha report.

  Tools to <u>support</u> the watch floor's most important decision!

- Allow targeteers to rapidly (less than one hour) develop and evaluate multiple COAs across multiple days via metrics.
  - Allow users to compare quantitative metrics in terms of expected total number of interdictions, total value of interdicted assets, and probability of detection and interdiction of each evaluated case.
  - Incorporate individual case reliability into the models, represent in the decision support interface.
  - Provide context-based probability of detection based on METOC, Target, & Sensor information.
  - Incorporate flow in the models to account for the probability of unreported events
  - Augment/disambiguate case criteria uncertainty using conditional probabilities generated from historical records.

15-minute Re-Targeting Recommendation
1-hour Daily Targeting Board Recommendation

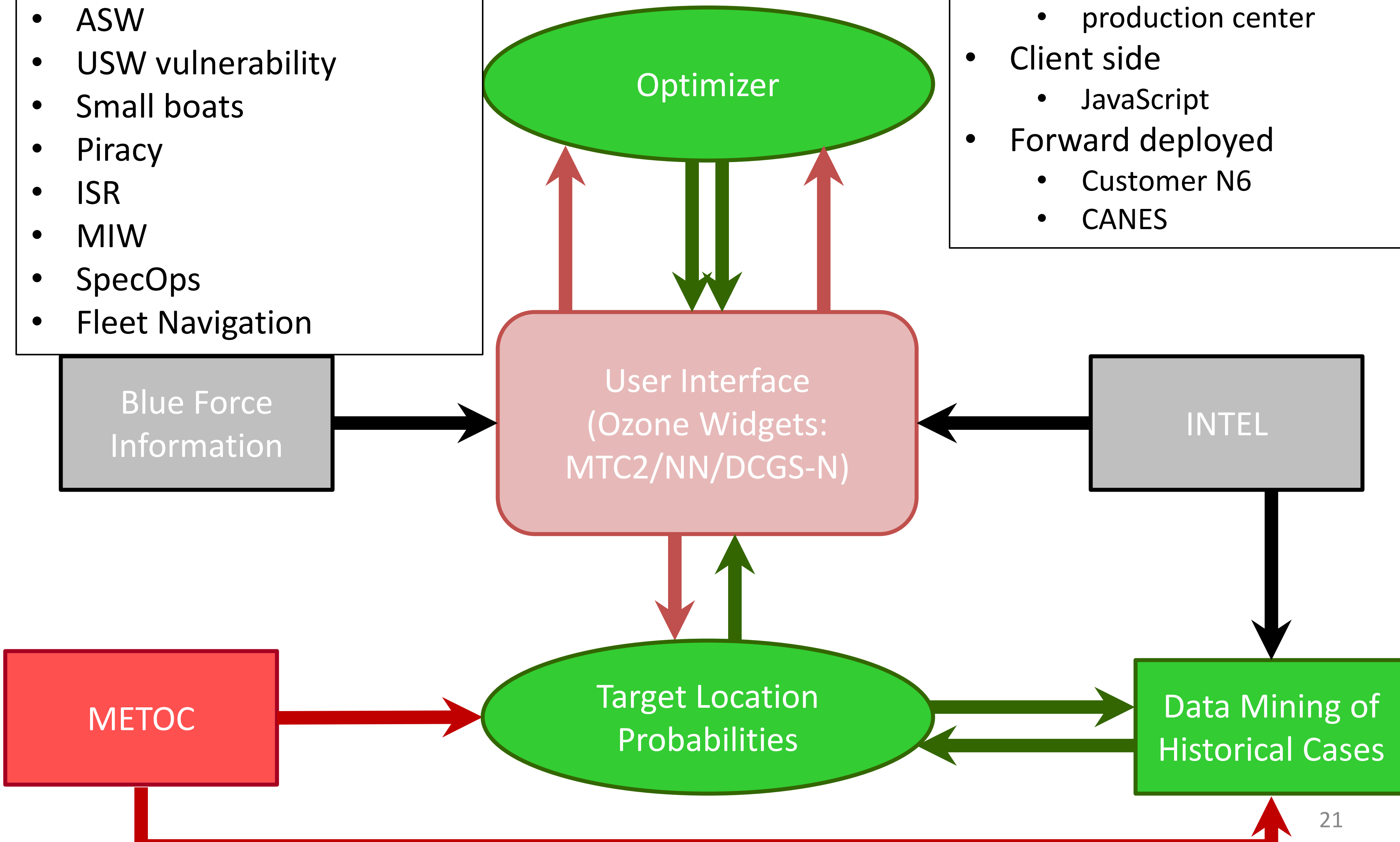
A Generic Optimization Framework?

Many possible mission areas:

- Illicit trafficking
- ASW
- USW vulnerability
- Small boats
- Piracy
- ISR
- MIW
- SpecOps
- Fleet Navigation

Explore the balance between:

- Reach-back
  - production center
- Client side
  - JavaScript
- Forward deployed
  - Customer N6
  - CANES



Definition for Proactive Decision Support…

- The application of automated information management tools to:
  - Provide data in a structured manner (information)
  - Highlight Missing & Discrepant data
  - Manage changing, ambiguous and/or conflicting information
  - *Develop a Smart Data Push / Pull*
  - Provide alternate hypotheses given what is Known / Unknown
  - *Enable human decision maker(s) to make time critical decisions faster and better than would otherwise be possible.*

"Get (and keep) the decision maker in the ball park…"

Why we need PDS & Uncertainty Management tools…

C4I Community of Interest:
Human Computer Interface for Decision Making (HCI-DM) Working Group

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Army

Ray Schulze, CERDEC;
Norbou Buchler, ARL HRED;
Liz Bowman, ARL CISD;
Kenneth Grippo, CERDEC

Navy

Jeffrey Morrison
ONR (703) 696-4875;
Mark Livingston, NRL

Air Force

Jason Moore, AFRL/RI
Erik Blasch, AFRL/LB
Paul Havig, AFRL/RH

OSD

Mr. David Jakubek

HCI for DM

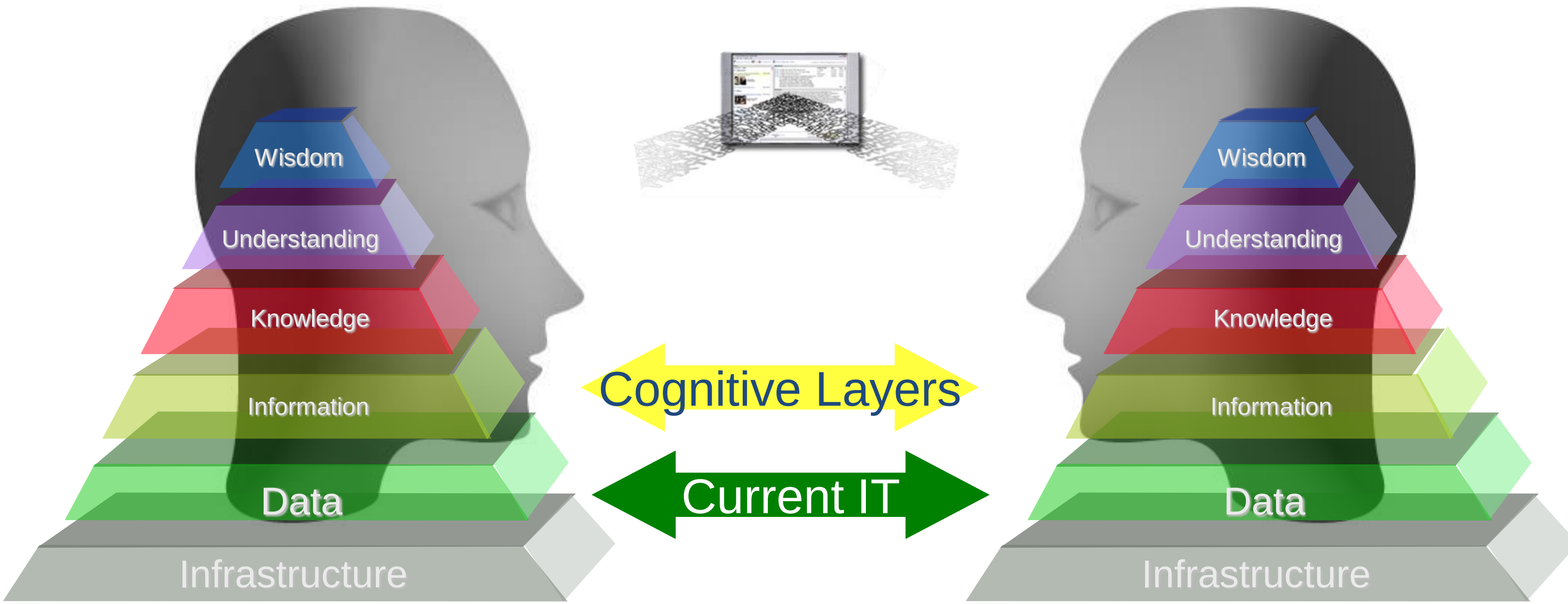
Motivation

- **Challenge:** Speed of Command requires timely delivery of useful information, to the right people at the right time, presented so as to support mission critical decisions.
  - Too much data - not enough information: Impedes decision making cycles.
  - Must focus on understanding of / designing for missions and tasks.
  - Information Technology design must address dynamic operational demands, and variable cognitive workload.
- **Perspective:** Need to exploit emerging HCI technologies to create an intuitive means of interacting and collaborating that focus on missions, tasks and the efficient /effective sharing of information across commands.
  - Must support higher-level cognition (reasoning, sense-making) and deliberative collaboration.
  - Must facilitate interaction with autonomous systems as information providers/consumers as well as between human decision makers.
  - Must design for high quality / effective & timely sharing despite limited bandwidth & intermittent connectivity.
- **Goal:** Increase exploitation of information that enable collaboration, shared knowledge, and effective decision support in a complex, dynamic, net-centric environment.
  - Enable transparency between Commanders and the functional systems used for collaboration and decision making
  - Integrate multi-sensory, haptic, augmented reality, and virtual reality technologies.
  - Create a "Cognitive Services Layer" within our C4I Infrastructure that allow the autonomous management of information based on dynamic operational requirements.
  - Human centered computing: improve system usability, task performance, and dramatically reduce training requirements and field service support

Ensuring Mission-based, timely, *Information* for Command Decision Making

Big Idea:
Decision Architecture

- The long range answer: Creating a new layer for the interface between humans & computers, and then humans with each other via computers that *move High Value Information separately from general data.*
- We should create a *Cognitive Layer* for Information Technology
  - Start with the cognitive equivalent of a TCP/IP packet,
  - Expand with a set of supporting Cognitive services & protocols.



Decision Architecture must provide a Cognitive Layer for C4I -
Manage the flow of data based on its expected value as <u>Information</u>

Operational Challenges: HCI for DM (1 of 3)

Challenge	Desired Capabilities	Research Opportunities (Priority)
Algorithms for valuing & sharing information based on task needs (vice simply distributing data)	**Imbue C4I systems with mission & task context awareness & dynamic information valuation algorithms**	• Develop Mission Context Engines linked to mission planning / management (1) • Research into dynamic modelling information needs tied to mission context (1) • Develop Information Triage Algorithms (1) • Develop tools & techniques for creating Low-Bandwidth Information Derivatives (1)
Need operationally useful Information Utilization / Effectiveness Metrics	**Able to dynamically evaluate mission utility, information quality & effectiveness of C4I technologies**	• Develop performance surface models that represent spectrum of possible outcomes at any given time in mission for assessment (1) • Develop techniques to assess human-machine system performance relative to possible outcomes (2)
Uncertainty Management	**Tools and techniques that enable decision making with uncertain information**	• Research decision making in Uncertainty & strategies for managing uncertainty (1) • Establish quantifiable & operationally significant error bounds in information sources and evaluate impact on team performance. (1) • Develop models for sensitivity analysis for missing & uncertain data in decision making (2)
C2 Display Utility Assessment	**Tools and techniques to evaluate display effectiveness during operational use**	• Research on information transaction measurement (2) • Algorithms for dynamically computing display utility / display effectiveness (1) • Development of DoD standards & employment protocols for User Defined Operational Picture (UDOP) widgets & services (2)

Operational Challenges for HCI for DM (2 of 3)

Challenge	Desired Capabilities	Research Opportunities (Priority)
Proactive Planning Decision Support	**Tools the capture, encode & reason about mission planning. Products must be human interpretable, machine manipulatable objects.**	• Research on tools and techniques for mission driven Information Brokering (1) • Research into appropriate units of analysis for mission planning (3) • Development of tracking algorithms to "chart the changes" in mission plan elements (2)
Information Provenance Pedigree	**Tools and techniques to maintain awareness of underlying information sources as data is fused & propagated across commands**	• Preserve & expose Pedigree / Provenance of mission critical information (1) • Technique for showing dependencies in hybrid/fused data (2) • Visualization for charting changes in fused data elements (2) • Algorithms to quantify information value to a decision maker given multiple factors, e.g. Missions, Tasks, Skills (1)
Low-Cost C2 Utility Simulation Testing Environments	**Develop & validate C2 processes through virtual constructive test & development**	• Develop C2 Test Task, vignettes that are common to DoD missions (2) • Develop agent-based simulations for common C2 missions (2) • Development of virtual agents for small unit operations (1) • Extend Human Interface Test Beds to evaluate the impact of information derivatives on team performance (1)
Machine Facilitated Collaboration for managing Autonomous & Complex Systems	**Design standardized protocols for effective & efficient information transaction for supervisory control of multiple autonomous systems**	• Research techniques for transacting key mission events & failures as they relate to a dynamic mission context. (1) • Develop machine encodable, semantic ontology, for task / mission context models (1) • Research the development of trust as a information exchange process (2)

Operational Challenges for HCI for DM (3 of 3)

Challenge	Desired Capabilities	Research Opportunities (Priority)
Model Command / Combat Decision Making for Machine Executable Components	**Reusable cognitive services that emulate low-level decision-making and enable doctrinally-based, higher-level, decision support**	• Develop Cognitive Services algorithms for SOA (1) • Research Behavioral Trajectory Modeling Techniques (1) • Develop Behavioral Anomaly Detection Algorithms (2) • Develop Proactive Decision Support Tools for missions (1)
HCI Test & Evaluation Simulations	**Test beds and tools for evaluation of alternative HCI design concepts prior to operational testing**	• Develop agent –based simulations of military C2 units (e.g. components of Regimental command center, Naval Strike Group)
Information Management for limited connectivity	**Strategies for smart-push and efficient, localized storage of high value, mission critical information**	• Develop operational data cache for information staging • Develop "Best Available Data" management schemes for bandwidth challenged environments
Information Derivatives - Text	**Develop semantic meta-tagging capabilities for structure & unstructured text**	• Develop tools for computing derivative information / "gisting" (2) • Trend analysis tools for text context (2) • Develop data analytic tools for hypothesis generation / texting (2)
Behavioral Anomaly Detection	**Personal (wearable) devices for sensing biophysical, biomechanical states with algorithms for detecting physiological & behavioral anomalies**	• Research to identify mission-specific tasks and normal bounds of physical effort (1) • Develop anomaly alert mechanisms to signal unexpected behaviors across command echelons(1) • Research for display of individual / team mission readiness & capabilities (1)

Acknowledgements:

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Dr. Krishna Pattipati, UConn

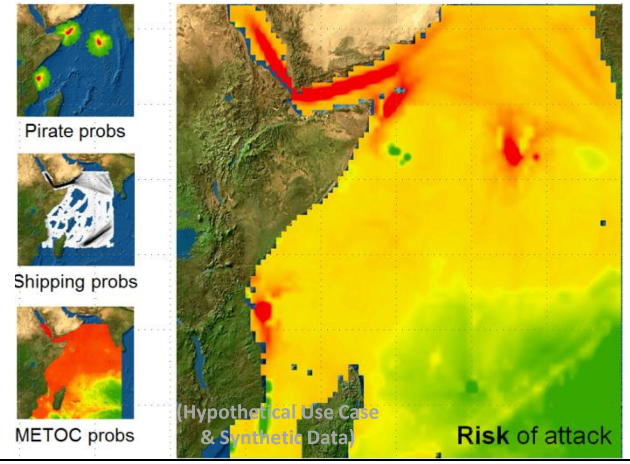
UNCERTAINTIES???

Pirate Attack Risk Surface (PARS)

Jim Hansen (NRL Monterey)

Project Objectives:

- Dynamically couple METOC and INTEL guidance to estimate and communicate the expected risk of pirates operating off the Horn of Africa (HOA) and in the Gulf of Aden (GOA) as a function of location and forecast lead.



Risk of pirate attack requires pirate probabilities, shipping probabilities, and environmental suitability probabilities.

Technical Approach:

- Combine INTEL, uncertainty, environmental forecasts, and pirate behavior information to predict the distribution of possible pirate locations.
- Construct probabilistic forecasts of vulnerable commercial ships.
- Estimate the probability of attack conditioned on the environmental conditions.
- Attack probability is the product of the pirate probability, shipping probability, and environmental suitability probability.

Accomplishments/Impact/Transitions:

- Successful transition and operationalization at the Fleet Numerical Oceanography and Meteorology Center (FNMOC, pirate probabilities) and the Naval Oceanographic Office (NAVO, shipping probabilities and environmental suitability).
- Briefed daily at NAVCENT and JOMOC (Northwood).
- ***Computerworld Honors Laureate*** (visionary applications of information technology moving businesses forward and benefiting society.)
- Technical foundation for ***Targeting in Uncertainty*** applications in illicit trafficking and anti-submarine warfare.