# Autonomy and Cooperation

**Michel Rixen**

**EGO workshop 2008**

# Environmental program: goals

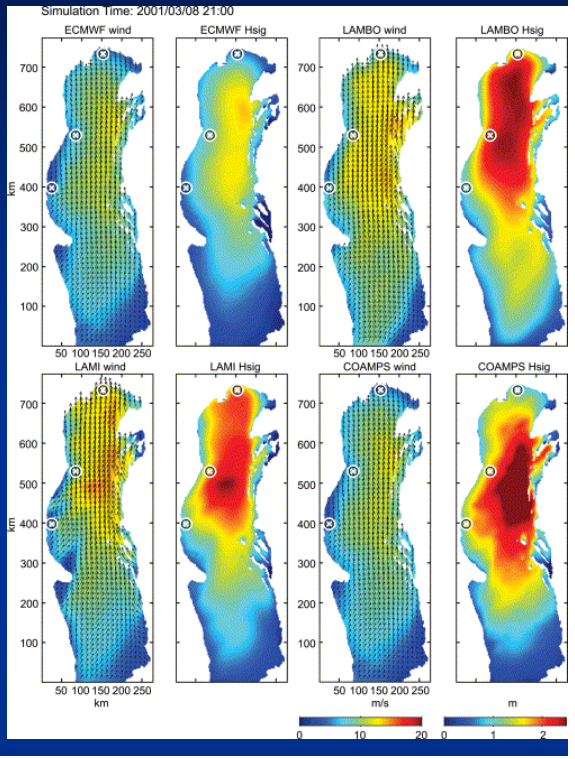
**Environmental knowledge/uncertainty management system:**

- **Assessment of uncertainties, risk and human factors in operational effectiveness and decision making**
- **Reduced uncertainties in environmental characterization and tactical predictions**

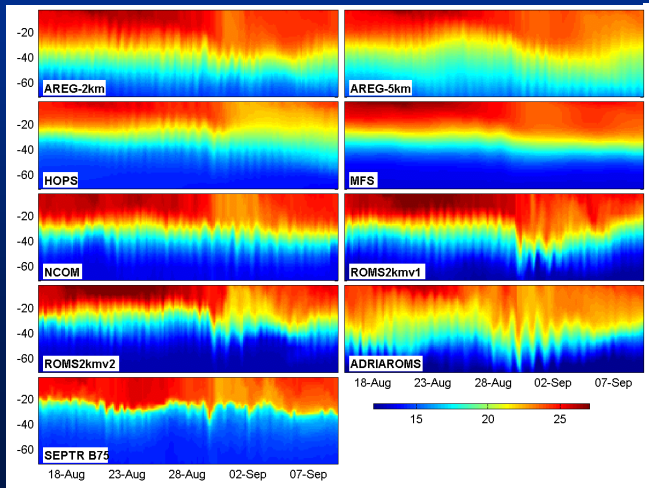
**Hypothesis: unknown area**

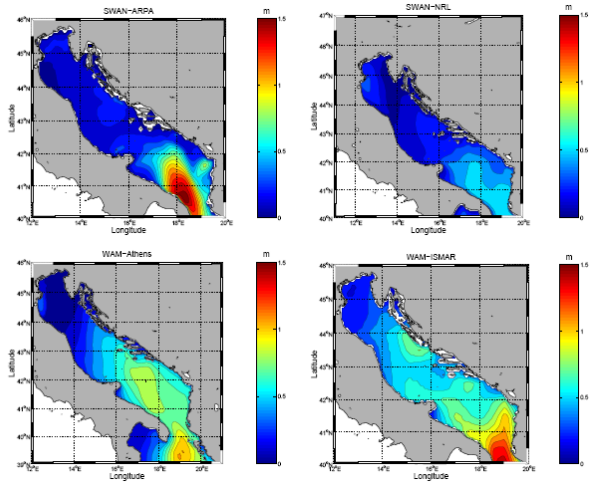
# Rationale: coastal region

- Highly variable
- Short spatio-temporal scales
- Limited observations (cf. Nyquist rule)
- Limited deterministic prediction tools
- Higher uncertainties
- Timeliness is even more critical
- Difficulties for decision makers




Low skill
Sometimes just noise
Uncertainty cascading



# Environmental knowledge model

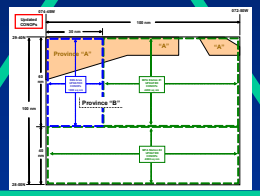
Uncertainties

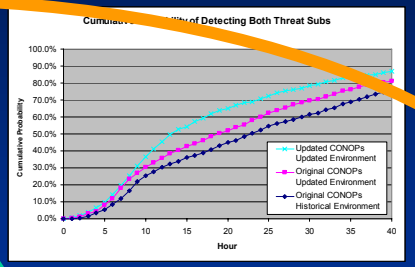
Feedback

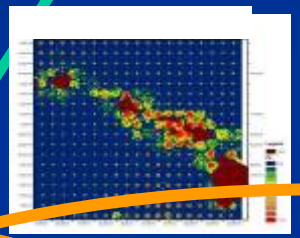
*Tier 3 – the Decision Layer*
- *Options / Courses of Action*
- *Quantify Risk*

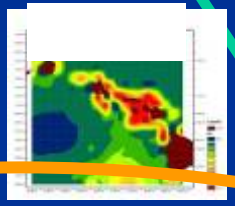
*Tier 2 – the Performance Layer*
- *Operational effectiveness*

*Tier 1 – the Environment Layer*
- *Search patterns*
- *Asset alloc.*

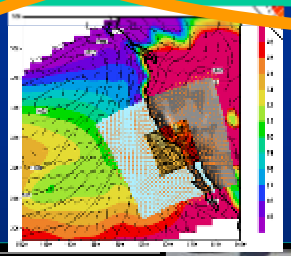


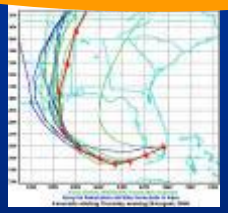



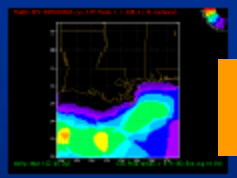





Task 2







Task 1


*Initial and Boundary Conditions*

Courtesy: CNMOC, adapted

# Context – reality - drivers

- Reduced number of ships
- Reduced staffing
- Increased fuel cost

- Reduce cost
- Improve performance
- Improve schedule

**Limited resources: focus when & where required**

# Autonomy

*Speed ←→ Endurance*

| | | |
|---|---|---|
| 4 kts<br>Hours | 3 kts<br>Days | 0.5 kts<br>Months |


## Gliders

- Persistent
- Steerable
- Wide area
- Vertical profile

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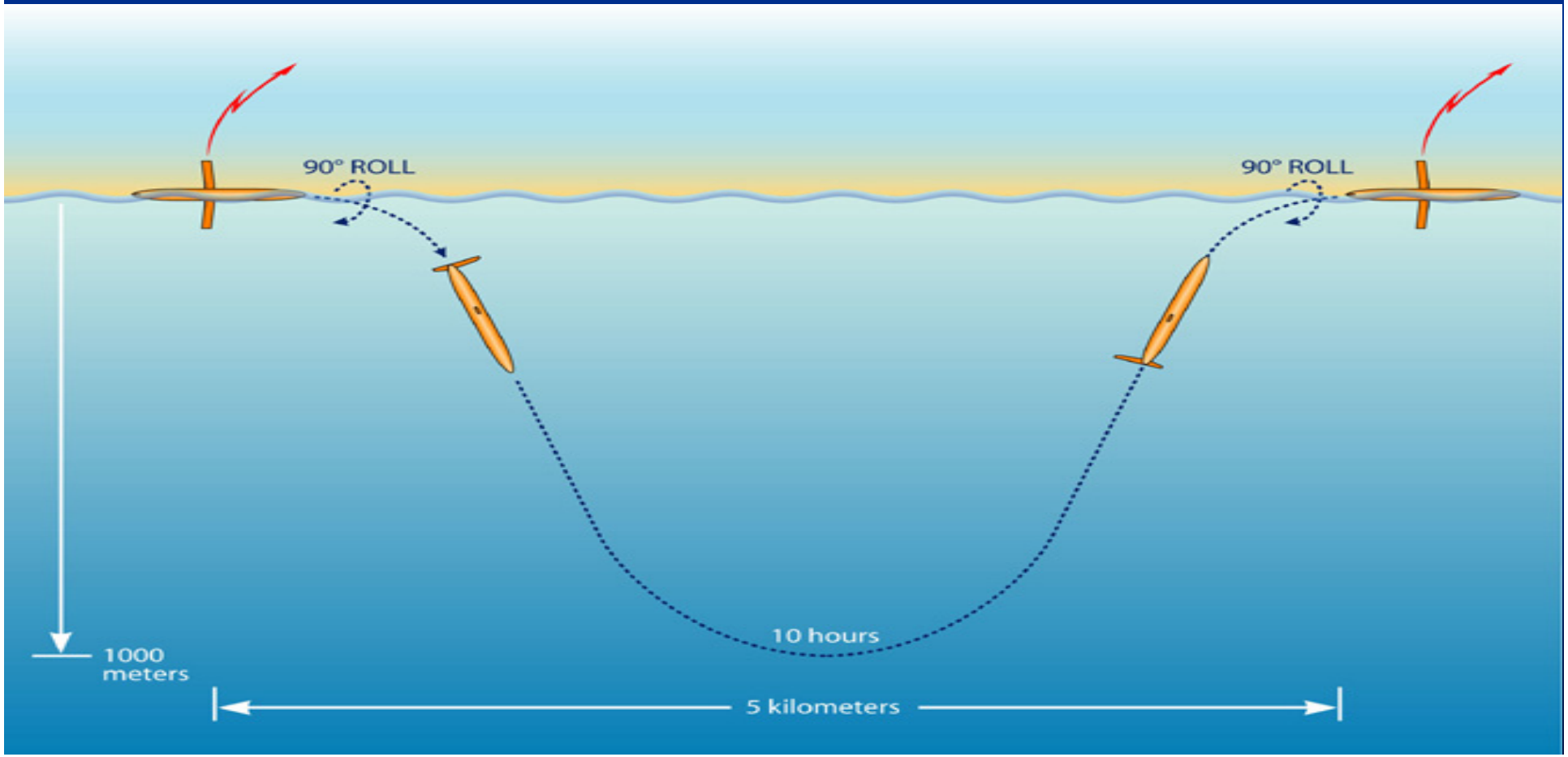
# Gliders Technology

- *Autonomous, covert (low signature), networked, persistent, scalable (desired cost, schedule, performance), adaptive, safe, low maintenance, cheap, ~expandable (?)*



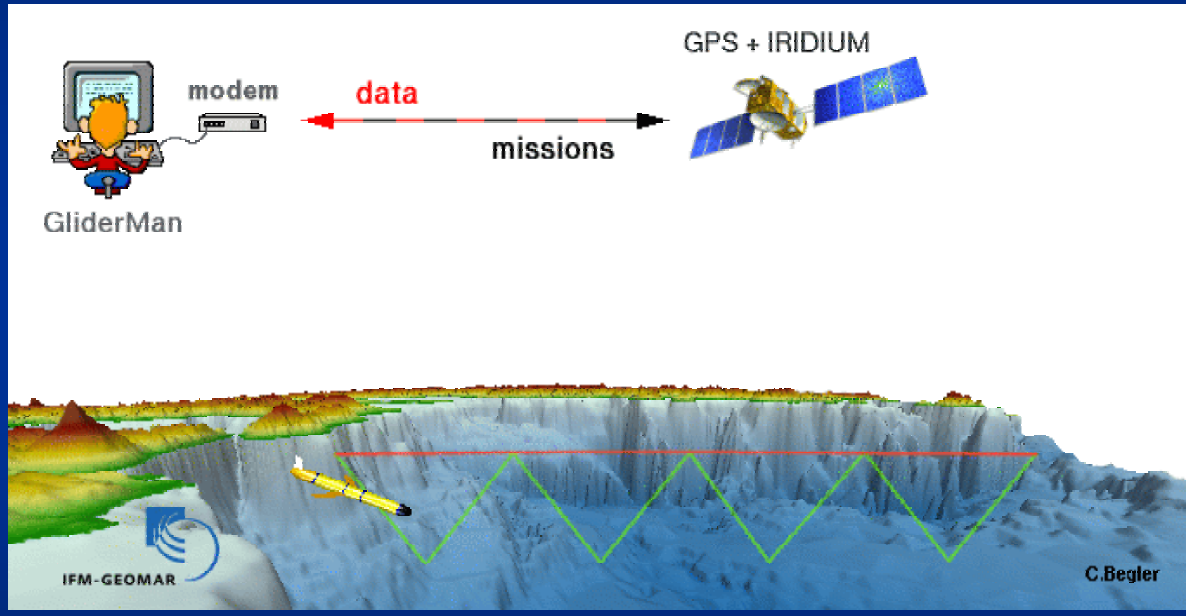
# Low Cost Hybrid AUV: FOLAGA

- Low cost platform (~ 15kEuro)
- Surface Capability
- Subsurface Propulsion with hydro-jet
- Subsurface Propulsion with buoyancy change
- Transportable by car

•Hovering at depth or bottom
•Designed for cluster work
•Multi-channel Communications: GPRS, Wireless LAN, Acoustic Modem

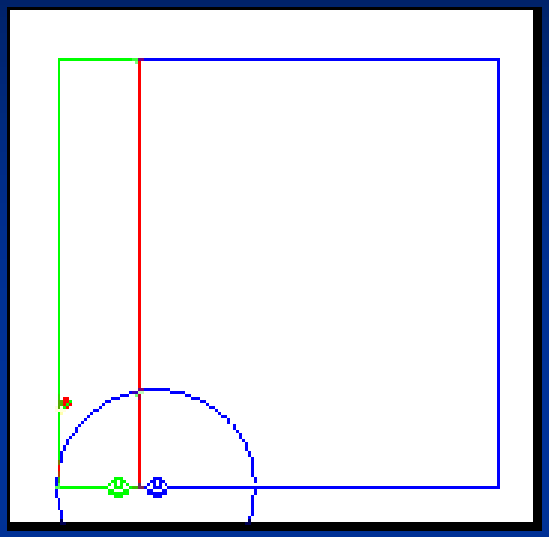
# Challenges

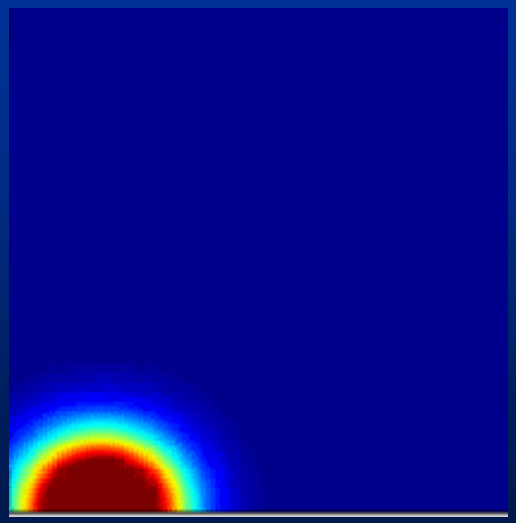
- Endurance
- Navigation
- Currents
- Bio-fouling
- Inter-operability
- Low bandwidth
- Logistics
- Clearances
- Customs
- *etc*



# Cooperation

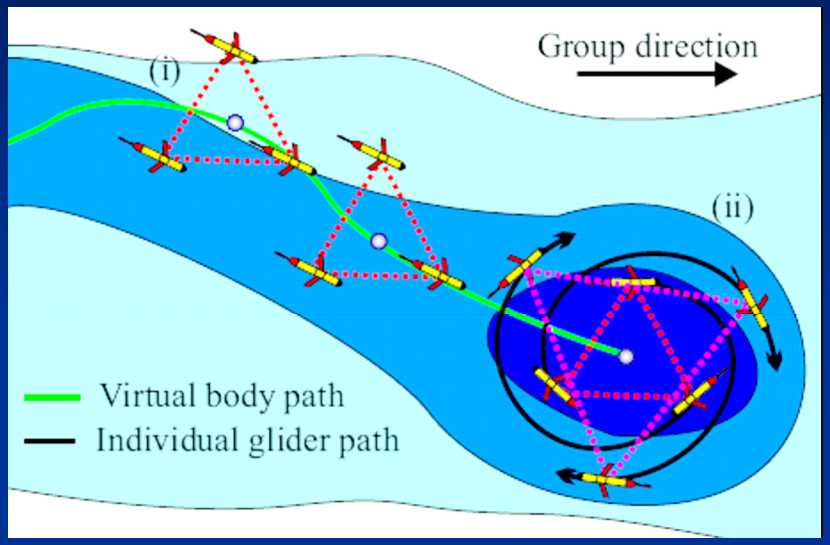
## Genetic algorithms

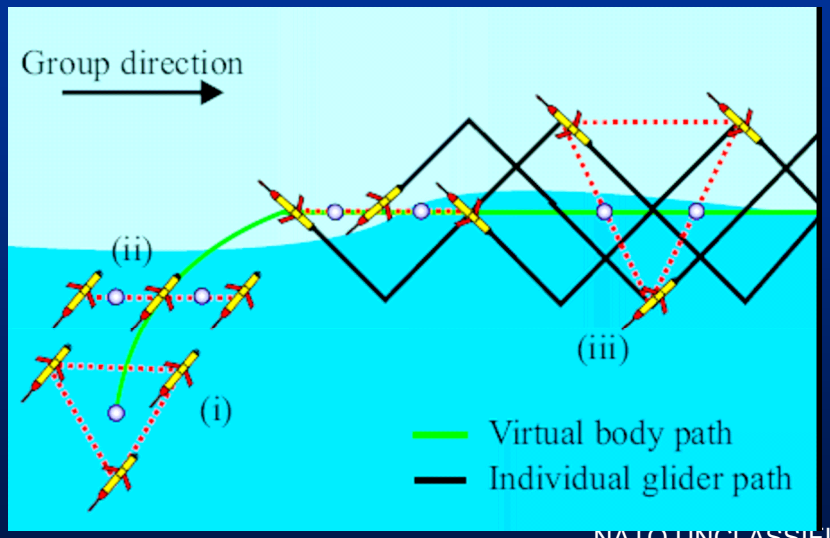




(Courtesy A. Caiti/ A. Alvarez)

## Optimal control theory



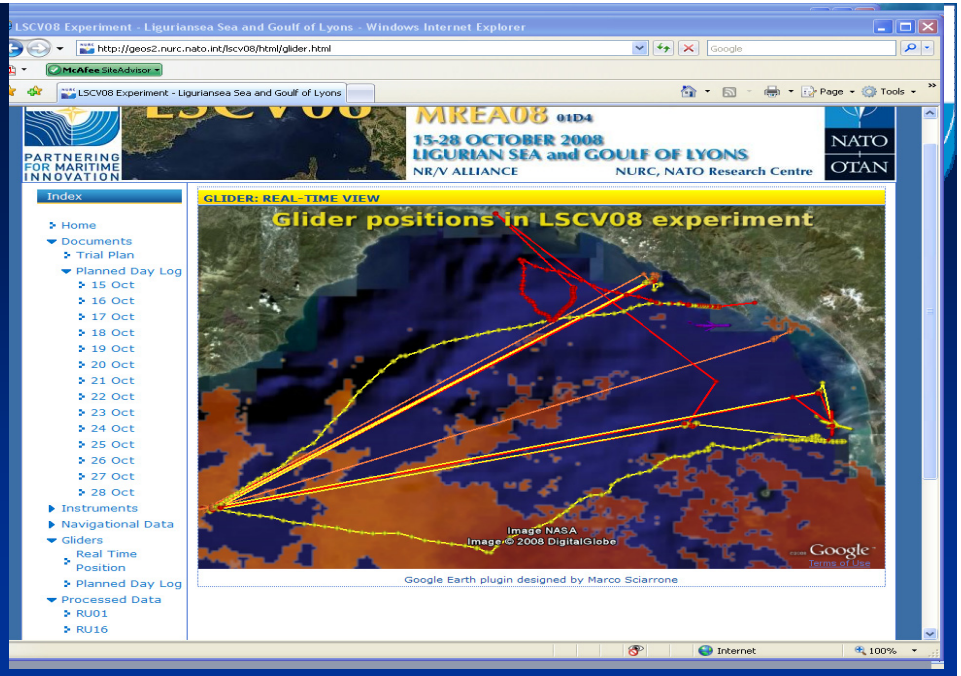




(Courtesy N. Leonard)

# Research Program on Gliders: Why Now?

- Initial development phase is ending. Next:
  - Payload Development
  - Hybrid systems
- Expand beyond REA:
  - Cooperative ASW
  - Undersea communications and networks
  - Marine mammals risk mitigation
- Industrialization beginning
  - need to influence now on specifications/design
  - interoperability

# Key events




- 2008
  - TSS 08
  - LSCV 08
  - Ocean Optics conf.
  - EGO 27-31 Oct 08
  - Decision support meeting 18-20 Nov 08
- 2009
  - BlackSea 09
  - BP09 – Ligurian Sea – March – with gliders (SIC A. Alvarez)
- 2010
  - REP10
  - REP conference: focus on autonomy & cooperation
- 2011
  - Operational test during a major exercise

# EGO workshop/school - NURC

- Objectives:
  - Review state-of-the art in Glider science
  - Bring glider community together
  - Way ahead:
    - S & T, R & D, specifications
    - Inter-operability
    - Collaborations
- ~100 people, 12 nations, 10 companies: “something’s going on”
- 27-29 Oct: scientific workshop
- 30-31 Oct: hands-on training
- geos2.nurc.nato.int/ego08
- Sponsors: ONRG and Italian Navy

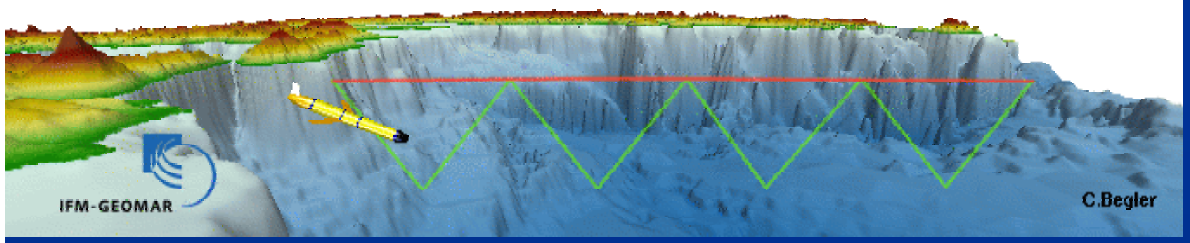
# Let's think "out-of-the-box"…

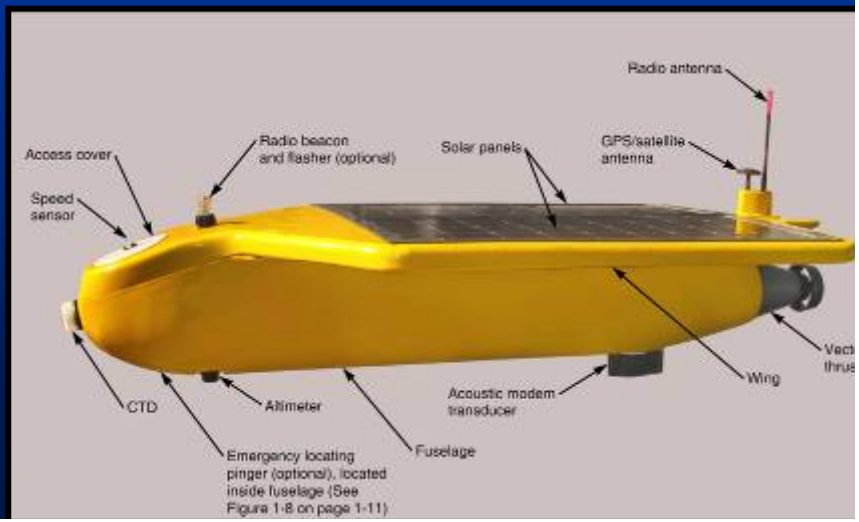
- Natural (vs. artificial) intelligence
- Endurance (24/24h, 7/7 days)
- Adaptive
- Scalable
- …

# Questions?

# SE require data: gliders?

## (covert+persistent+adaptive+scalable+cheap+expandable)

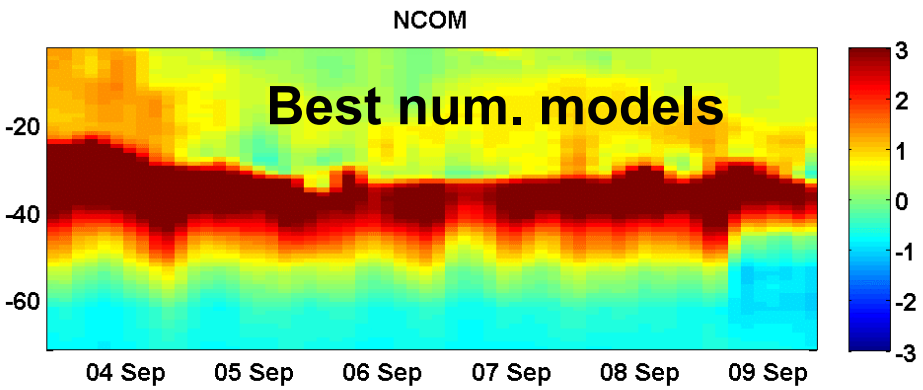



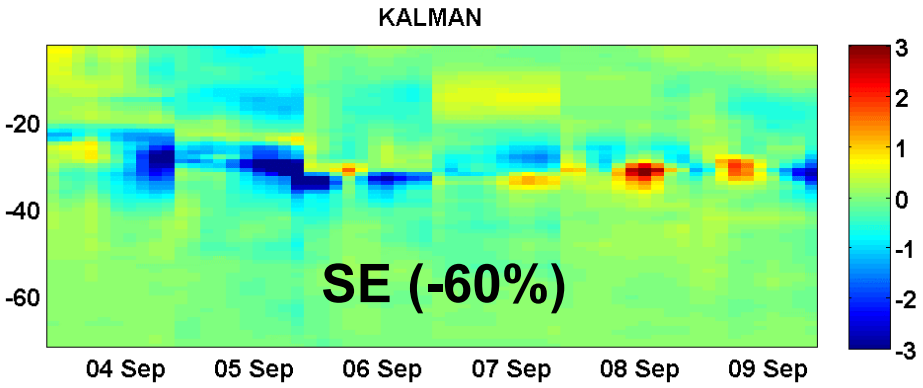




SAUV for AO Boundary Layer

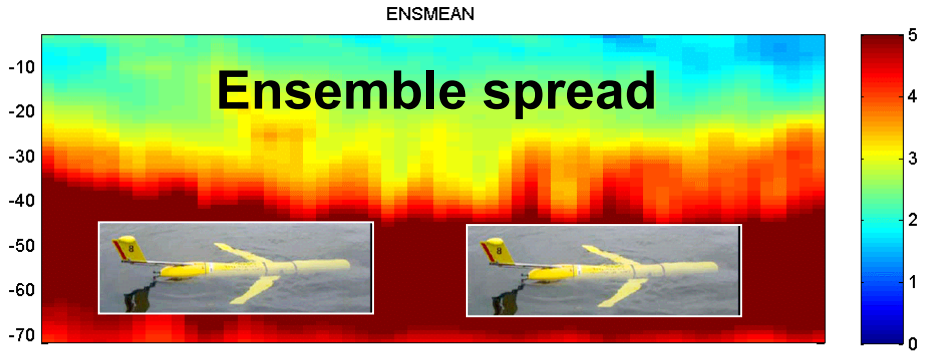
# Improved predictions
# Reduced uncertainties

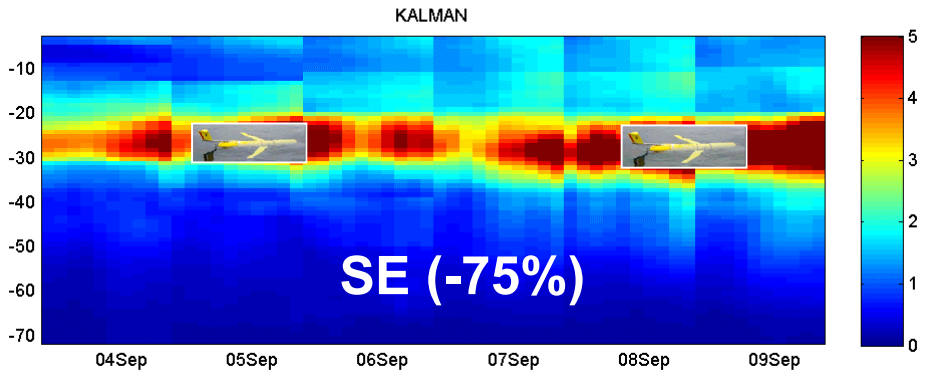
## Prediction error




## Uncertainty



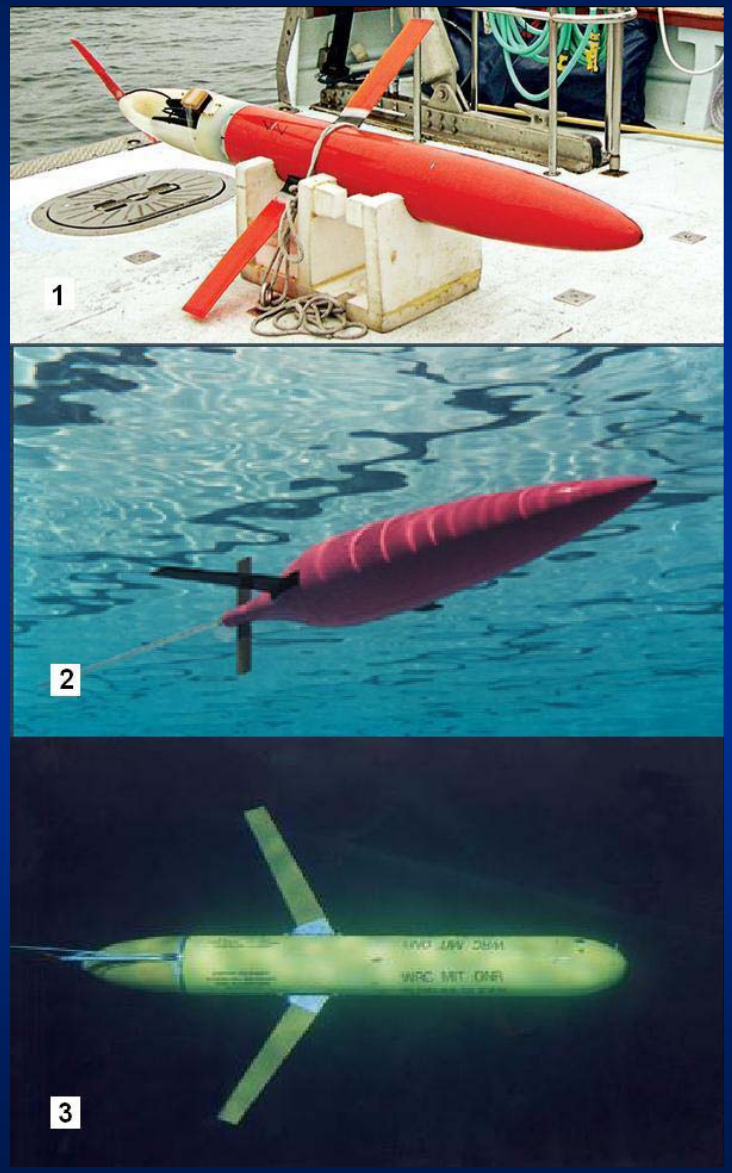
# Research Program on Gliders at NURC: way Ahead

- Begin procurement of approximately five gliders
- SPOW plans updated to include gliders
  - MILOC
  - MMRM
  - CASW
  - Underwater communication gateways
- Coordinate Specialist team within NATO (MCG2/NNAG)

# Summary

- Gliders provide a unique capability for monitoring the undersea environment
- First generation gliders are mature and reliable platforms
- Research for dual applications is needed now
- NURC has the right experience and expertise to provide leadership for NATO

# Glider technology




First generation gliders: three operational gliders have been produced through ONR

1: Spray
(manufactured by Bluefin)

2: Seaglider
(manufactured by Seaglider Fabrication Center of the University of Washington)

3: Slocum Glider
(manufacrtured by Web Research Corporation)

# Battlespace Environmental Superiority

## Objective

- High resolution battlespace environmental characterization and prediction (1A2, 1B5, 1D4)
- Environmental impact on operational decision making (1A5, 1D4, 5D4)

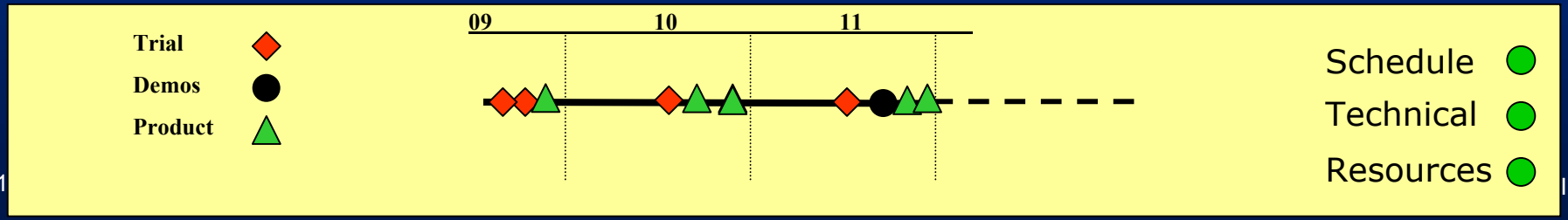
- Contributions to REP, iMETOC

## Payoff/Importance

- Improved predictive capability in littoral regions
- Robust decision making with known level of risk
- Partners: USA, ITA, FRA, DEU, ESP, USA, GBR, CAN, TUR, GRE

## Products

Environmental Knowledge/uncertainty management system



# Summary: BES=integration

- Area focus shifts to a knowledge model to support operational decision making
- Goal: environmental information & uncertainty management
  - Characterization of the operating area
  - Environmental impact on operational effectiveness
- Critical elements of the REP and iMetoc
- Transition Path: National METOC centres, iMETOC lead nations, REA COE, MCCIS (possibly)

# Updates/changes to draft SPOW09

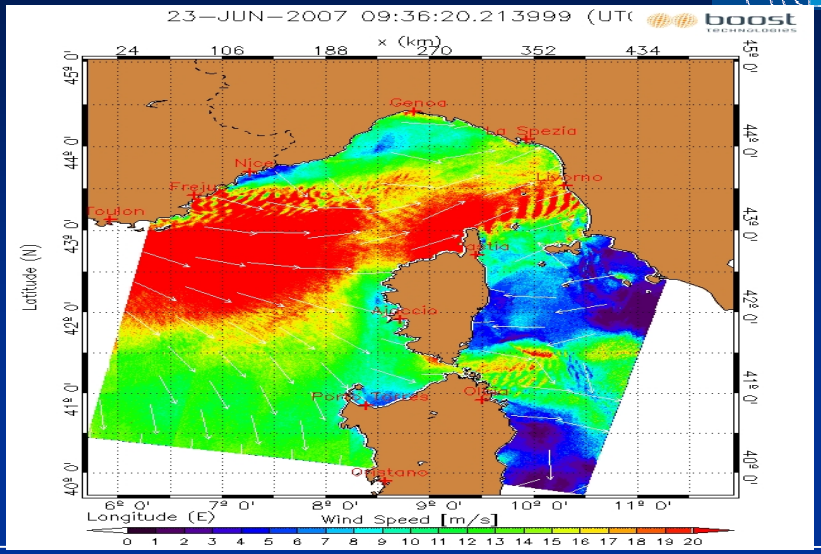
Following comments of the SCNR, ACT, France, UK and others:

- Level of effort in task 1 decreased on
  - coupled ocean-wave-atmosphere model
  - coupled bio-optical ocean model reduced
- Close liaison with the MILOC REA CONCEPTS WG & NC3A
- REP experiment in 2010 and 2011
- Risk metrics in task 2a: will be defined in collaboration with partners and nations

# Air-Sea Interaction Effects

## Objective

- Improve littoral METOC algorithms for tactical application through development and evaluation of:
  - Parameterizations
  - Stochastic approaches
  - Dispersion applications




## Payoff/Importance

- Improved forecast and diagnostic skills over littoral areas for Expeditionary Operations and NATO Reaction Forces (NRF)

- Partners: DEU, FRA, GBR, ITA, NLD, PRT and USA

## Products

Re-locatable forecast model

**Progress:**

- Data Analysis from the LASIE experiment.
- TSS-08 (Black Sea, Sea of Marmara etc).
- Implemented and tested ocean/atmosphere coupled system: COAMPS-OS + NCOM (JRP with NRLMRY).
- Regional Ocean Modeling System (ROMS) configured for Sea of Marmara.

Schedule and products reduced due to departure of Lead Scientist
This effort ends in 08, as planned

| | |
|---|---|
| Schedule | 🟡 |
| Technical | 🟢 |
| Resources | 🟡 |



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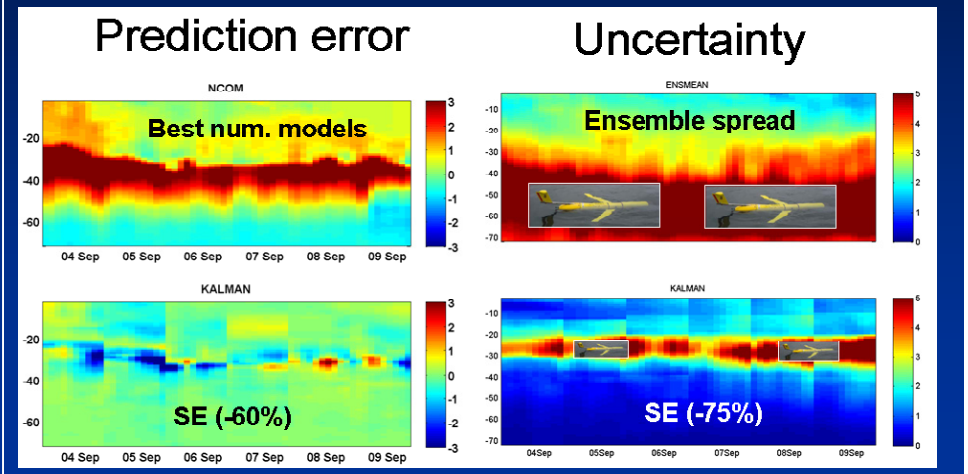
# Shallow Water Ensemble Prediction

## Objective

- Develop and validate shallow water ensemble modelling techniques
- Improve littoral and near-shore predictions for tactical applications




## Payoff/Importance

- Improved predictive capability in littoral regions
- Quantification of METOC uncertainty
- Partners: ITA, FRA, DEU, ESP, USA, GRE

## Products

Multi scale ensemble prediction tool

### Progress

- Network-enabled Web-GIS GUI and OGC compliant interface with super-ensemble tool
- Journal article

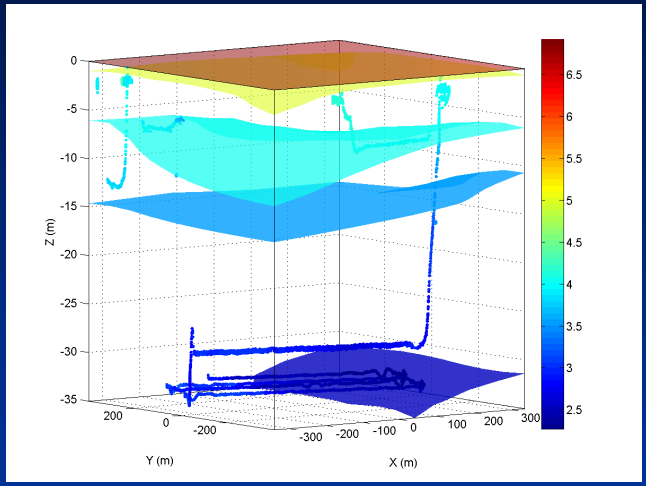
All products on schedule to be delivered as planned.
This effort ends in 09, as planned

Schedule ●
Technical ●
Resources ●

# Battlespace Characterization

## Objective

• Integrated approach to provide near real-time METOC data collection capability in denied areas using systematic methods and tools to assimilate remote sensing, autonomous vehicles and *in situ* measurements




3D thermal field estimated from fusing data satellite (surface layer) and AUV (scattered dots) during COLOSSUS 2 experiment

## Payoff/Importance

• Capability to collect local METOC data for "out of area" operations in unknown or denied areas.

• Partners: GBR, ITA, PRT and USA

## Products

• Algorithms for fusion of in-situ, glider and remote sensing data for real-time METOC characterization

## Progress

• EGO Workshop

•Tested methods for fusion autonomous vehicles, remote and *in situ* sensors.

• Initial development of optimal network topologies for wide area littoral monitoring

All products on schedule to be delivered as planned.

This effort continues in BES, Task 1; Planned completion in 10

Schedule

Technical

Resources



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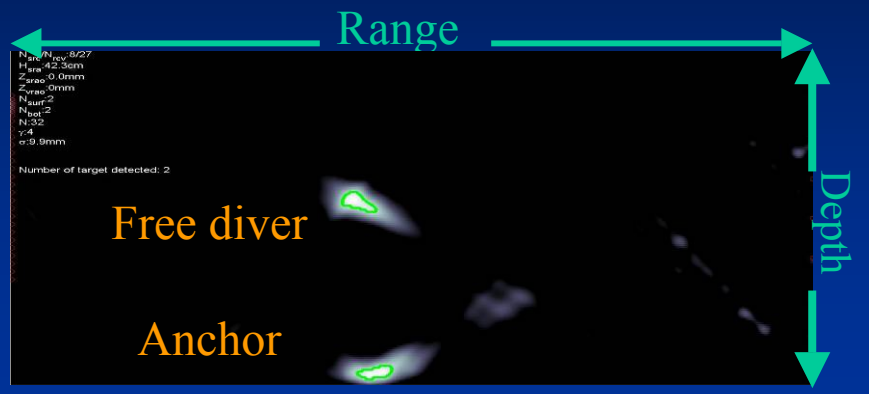
# High Frequency Prediction Capabilities and Environmental Effects

## Objective

- Improved prediction capability for High Frequency (5-50KHz) acoustic propagation
- Analysis of high frequency features and potential applications




## Payoff/Importance

- Improved prediction of acoustic propagation in ACOMM frequencies
- New method for intruder detection in ports and harbors using ACOMM frequencies
- Partners: FRA, POR, USA

## Products

- Improved predictive models for underwater comms
- Use of HF acoustics for port protection, specially tomography and acoustic tripwire

## Progress:

- Radar 07 Data Analysis
- ATW-08 Sea Trial and analysis
- JASA paper and Patent on tripwire

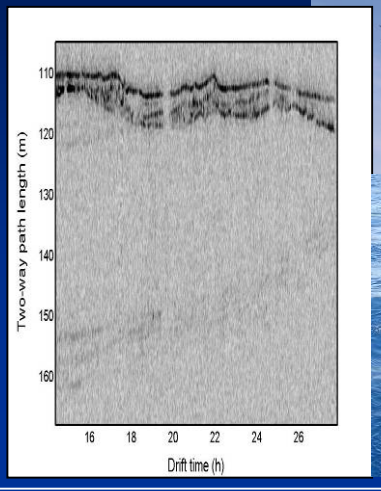
Schedule
Technical
Resources

All products on schedule to be delivered as re-planned.
This effort ends in 08, as extended

# Improved Acoustic Prediction

## Objective

- Develop and demonstrate methods to improve real time prediction of sonar performance.
  - Seabed reflection properties obtained using ambient noise inversion
  - low cost vertical line array (VLA)
  - directly used in acoustic range prediction tools




## Payoff/Importance

- LTCR "All weather detection of Submarines"
- Partners
  - CAN, GBR, NLD, USA

## Products

- Prototype real-time autonomous passive system

## Progress:

- Algorithms for deep bottom profiling & reflection properties using ambient noise
- System performance study
- Interface with shore propagation models
- Algorithms for target detection using noise

All products on schedule to be delivered.
This effort ends in 08, one year early

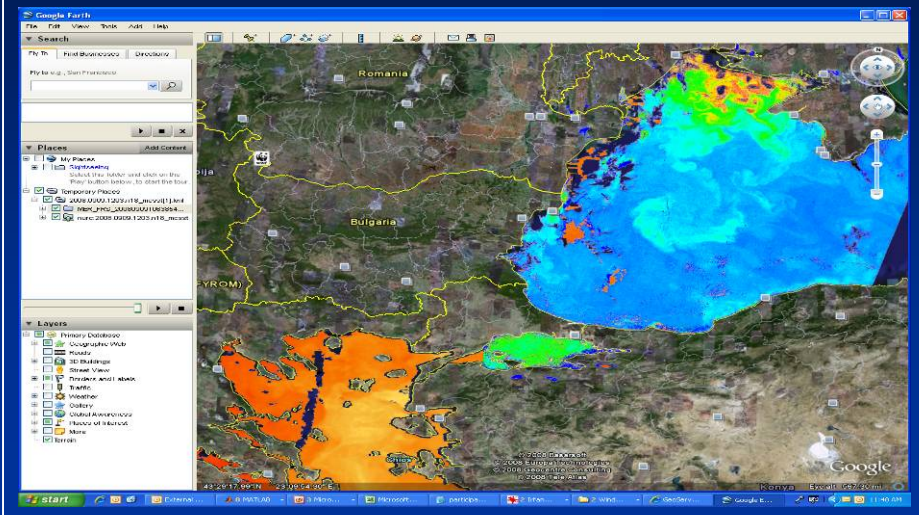
Schedule ●
Technical ●
Resources ●

# Operational Decision Support Tools

## Objective

A flexible prototype decision support system that assesses the impact of the complex environmental picture on operations:

- Suitable for the challenging littoral zone
- Automated, network-enabled decision aid tools
- Provide reliability indices of the decision




## Payoff/Importance

- Operational decision making using knowledge of METOC data uncertainty
- Partners: CAN, FRA, ITA, USA, NC3A, EU-JRC, ESA, NASA

## Products

Automated Decision Support Prototype using METOC Data uncertainty

**Progress:**

- Ligurian Sea Cal/Val Sea Trial
- Decision support workshop
- Co-sponsor Ocean Optics XIX
- Initial X-Band wind algorithm for Terra-SAR-X and Cosmos/Skymed

All products on schedule to be delivered as planned.
This effort continues in BES, Task 2, Planned completion in 10

| | |
|---|---|
| Schedule | ● |
| Technical | ● |
| Resources | ● |

# Measure of Performance (MoP): BES aim

- Cost: environmental characterization cost: -25%
  - Autonomous underwater platforms instead of ship-based operations
- Schedule: decision making time: -25%
  - Automated model-data fusion and group decision techniques
- Performance: prediction skill: +10%
  - Above best available model
  - Focus on sound speed profiles

# Battlespace Environmental Superiority

- Context:
  expeditionary operations/NRF
- Focus:
  coastal region
- Assumption:
  denied/unknown area
- Aim:
  reduced env. uncertainty for increased performance
- Customers:
  commander in the field, NRF, iMETOC lead nations, MCG, nations, ACT
- Concepts:
  REP, iMETOC
- Applications:
  CBRN, EM propagation, TDAs, mine-drift, S&R, *etc*

# Environmental knowledge model

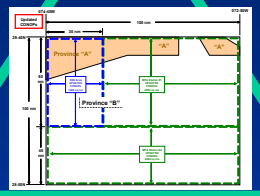
*Tier 3 – the Decision Layer*
- *Options / Courses of Action*
- *Quantify Risk*

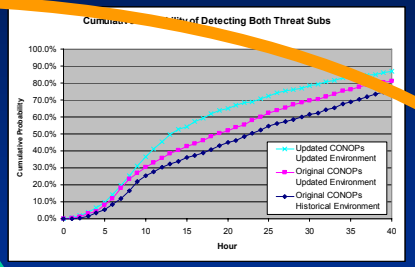
*Tier 2 – the Performance Layer*
- *Operational effectiveness*

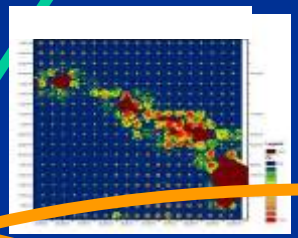
*Tier 1 – the Environment Layer*
- *Search patterns*
- *Asset alloc.*

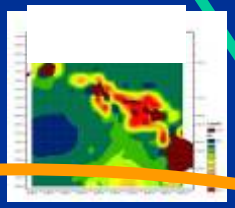
Uncertainties

Feedback

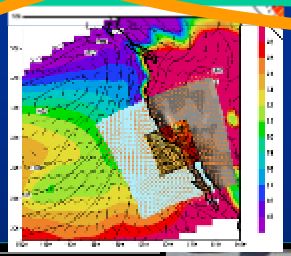


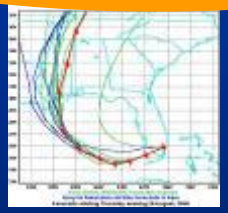


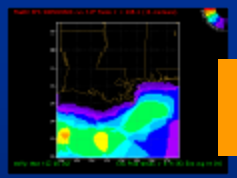





Task 2







Task 1

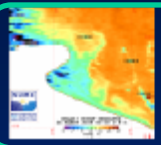

*Initial and Boundary Conditions*



Courtesy: CNMOC, adapted

# BES TASK 1

## MONITORING




1a

## Adaptive sampling



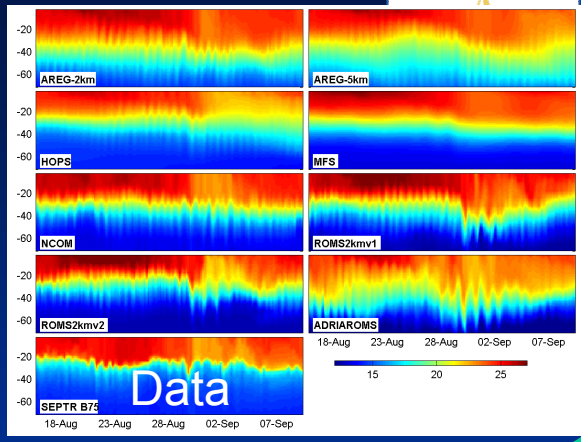
1b

## Data Assimilation & coupling

1c

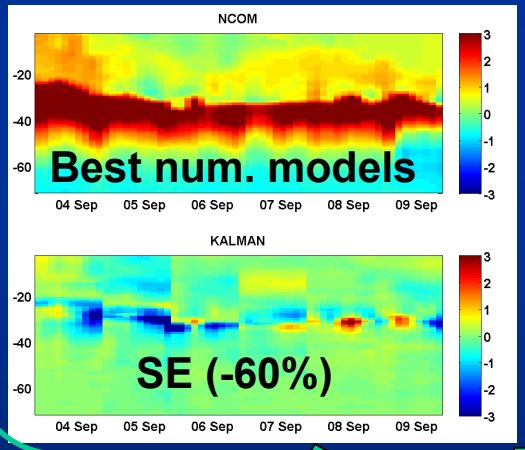
## PREDICTIONS

NURC



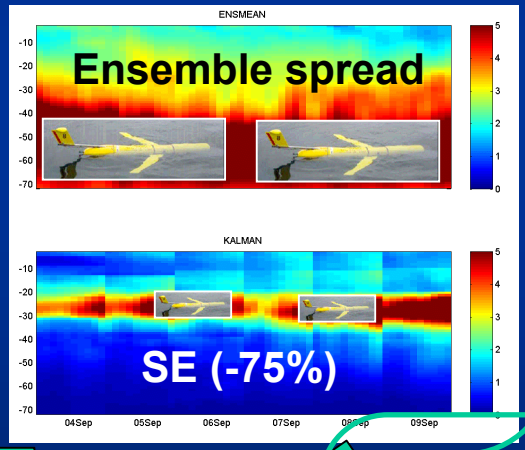

# BES TASK 2

## Prediction error



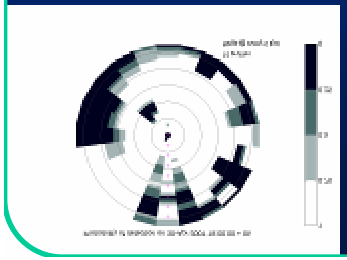

## Uncertainty

2b

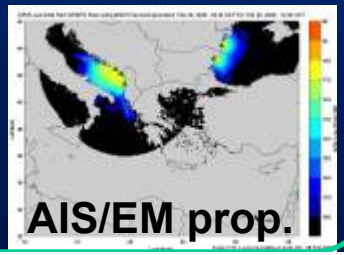



## SE Model-data fusion

## Detection range prediction

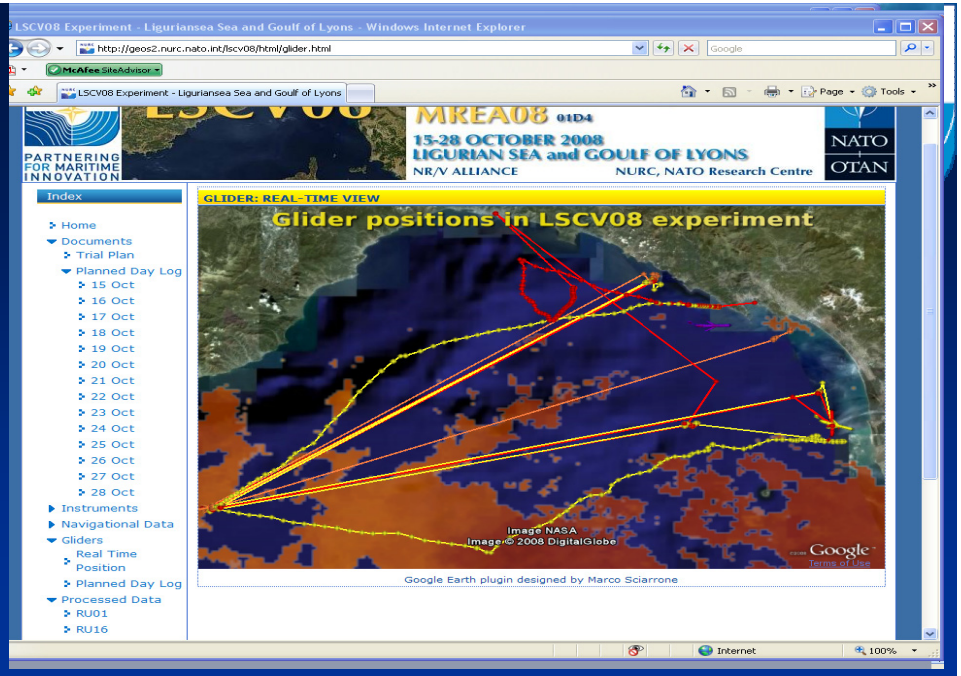



2c




2a

# Key events




- 2008
  - TSS 08
  - LSCV 08
  - Ocean Optics conf.
  - EGO 27-31 Oct 08
  - Decision support meeting 18-20 Nov 08
- 2009
  - BlackSea 09
  - BP09 – Ligurian Sea – March – with gliders (SIC A. Alvarez)
- 2010
  - REP10
  - REP conference: focus on autonomy & cooperation
- 2011
  - REP11 Operational test during a major exercise

# REP10

- Objectives:
  - coordinated fleet (20+) of gliders
  - Improve operational effectiveness and decision making exploiting uncertainty predictions
- Dates: early summer 2010 (TBC)
- Area: Alboran Sea
- Context: heavy maritime traffic, strong currents
- Coordination by NURC
- Data sharing: TBD depending on partnership, but more outputs expected if open sharing whenever not sensitive
- Preliminary interest: USA, GBR, ESP, FRA, ITA, CAN, DEU, AUS, etc
- 1st preparation meeting early 2009: 9-11 March 2009 (TBC)
- REP11: testing under quasi-operational conditions