Buoy Tracking using Monte-Carlo Techniques
(Trajectory Forecasting using Optimized Ocean Ensembles)

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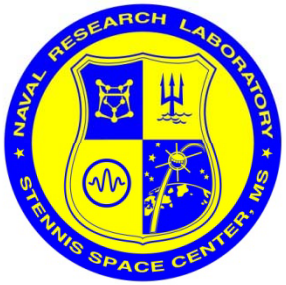


Marine Rapid Environmental Assessment 2010

Villa Marigola, Lerici, Italy
21 October 2010

Outline

System Components

- NCOM Ocean Model
- NCODA Assimilation System
- Surface Field Drift Model
- Relative Dispersion Maps and associated products

Past and Present Efforts

- Normal Mode Analyses
- Lagrangian Variational Analysis
- Ocean Ensembles
- Buoy Forecast Optimization via ensembles

Are we meeting the requirements?

- Primary metric is separation between observed/modeled buoys
- 5.6 km/24-hrs drift goal
- 22.2 km/24-hrs drift threshold

In Situ Environmental Characterization:

- Extend time horizon on drift from 4-8 hrs to 24-48 hrs

Motivation

Placement of Active ASW Distributed Systems (PAADS): One aspect of the development require the usage of ocean currents to assist:

- planning sonobuoys requirements
- predict sonobuoy networks acoustic coverage
- optimize launches
- monitor “holidays” in search areas
- assist tactical decisions

Challenge is to set up an operational forecast solution:

- with performance similar to the analysis solutions
- that’s easy to request, run and analyze results
- providing robust error forecast statistics to monitor “holidays” and assist risk analysis
- providing forecast position error distributions over time and space to solve array optimization issues

Past work within the project has investigated:

East Asian Seas Forecast System (EAS16)

Based on Navy Coastal Ocean Model (NCOM)
~8 km resolution
Legacy system, Was first used for LWAD07 support

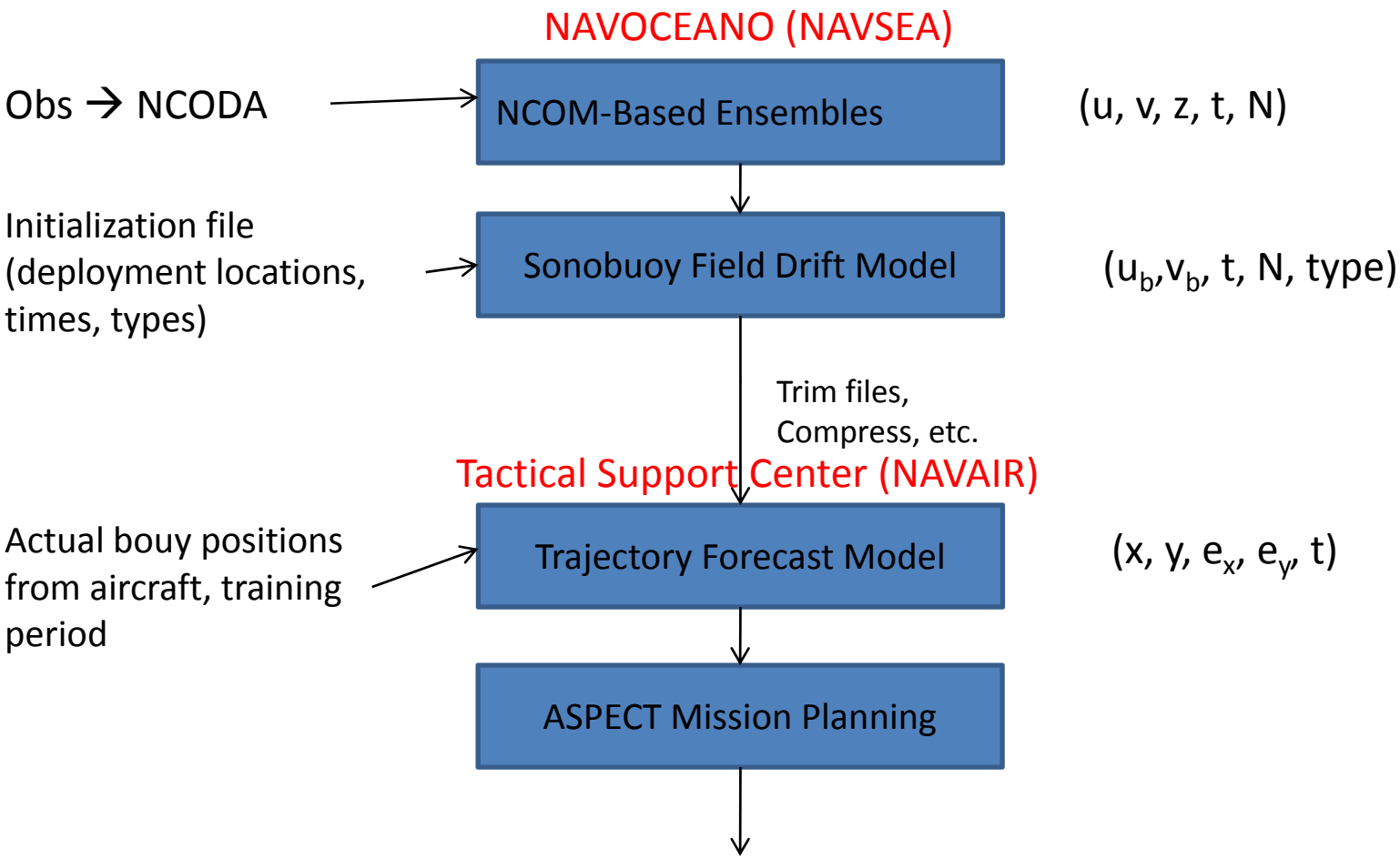
Methods that improve model velocity fields by blending them with Lagrangian observations

LAVA – Lagrangian Variational Analysis; correction is based on minimizing the difference between observed drifter positions and model forecasted positions (RSMAS)

NMA - Normal Mode Analysis; based on an expansion on normal modes, uses velocities along the trajectory as hard constraint on cost function (U. Delaware)

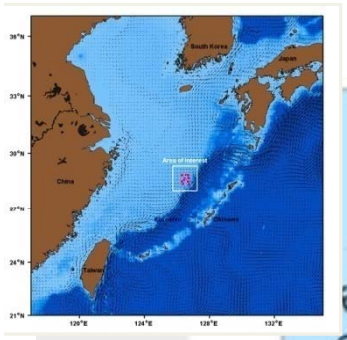
Ocean Ensembles (unoptimized and optimized)

Conceptual Flow Chart

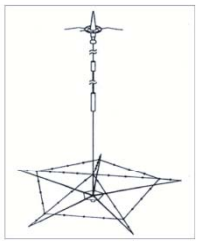


- Decide new deployments (# bouys, types, positions)
- Forecast of acoustic coverage
- Optimal network operation model (multistatics combinations and sonar modes)

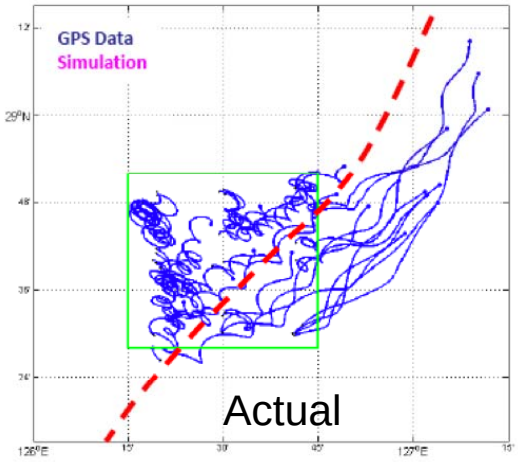
TESTING DATA: LWAD07-2 is the most comprehensive Sonobuoy/surface drifter data set available for testing

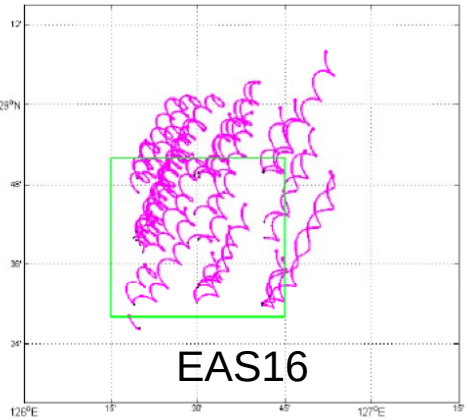


RELO/NCOM model domain



29 CDMR Sonobuoys on site between Oct. 9 to Oct 13 2007

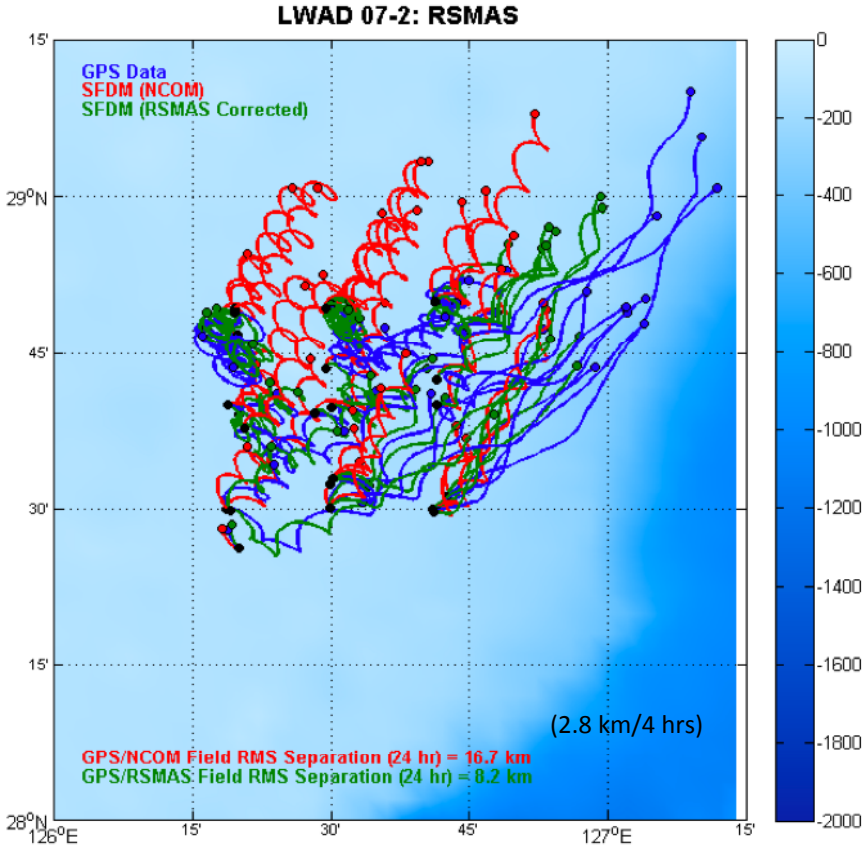




2 basic flow regimes (western side characterized by shelf Dynamics with a significant tidal component; eastern side Dominated by highly energetic meandering of the Kuroshio

Lagrangian Variational Analysis (LAVA)

Correction is based on minimizingthe difference between observed drifter positions and model forecasted positions (RSMAS)

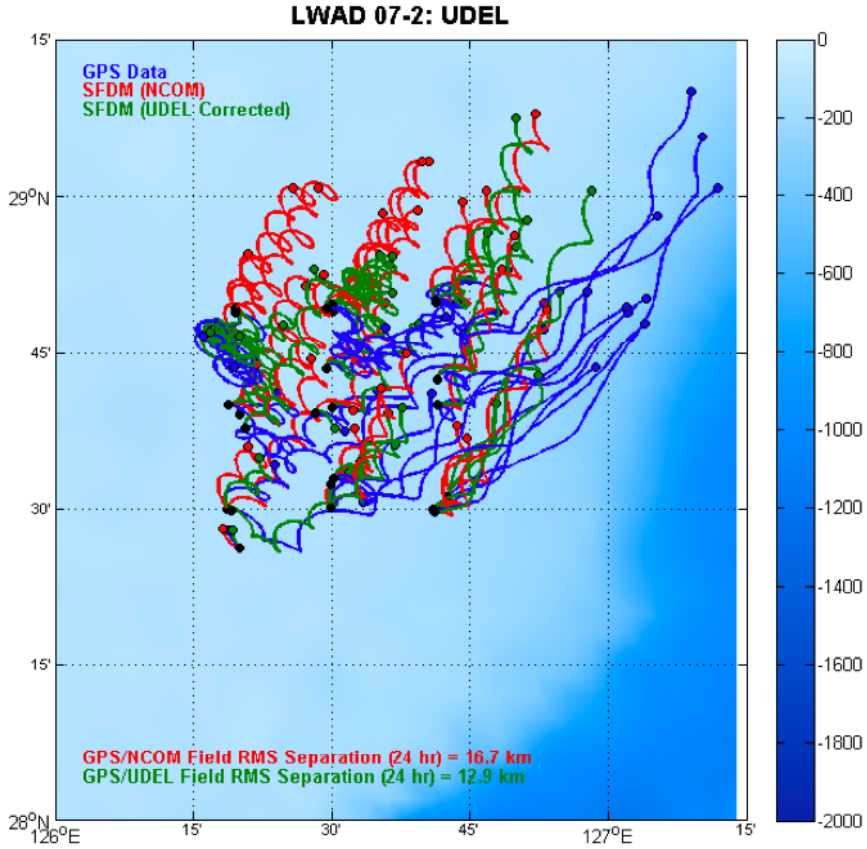


Green - LAVA predicted drift after blending In the buoy GPS data

24 hour RMS drift error reduced from ~15 km to ~7 km

Normal Model Analysis (NMA)

Based on an expansion on normal modes, uses velocities along the trajectory as hard constraint on cost function (U. Del.)

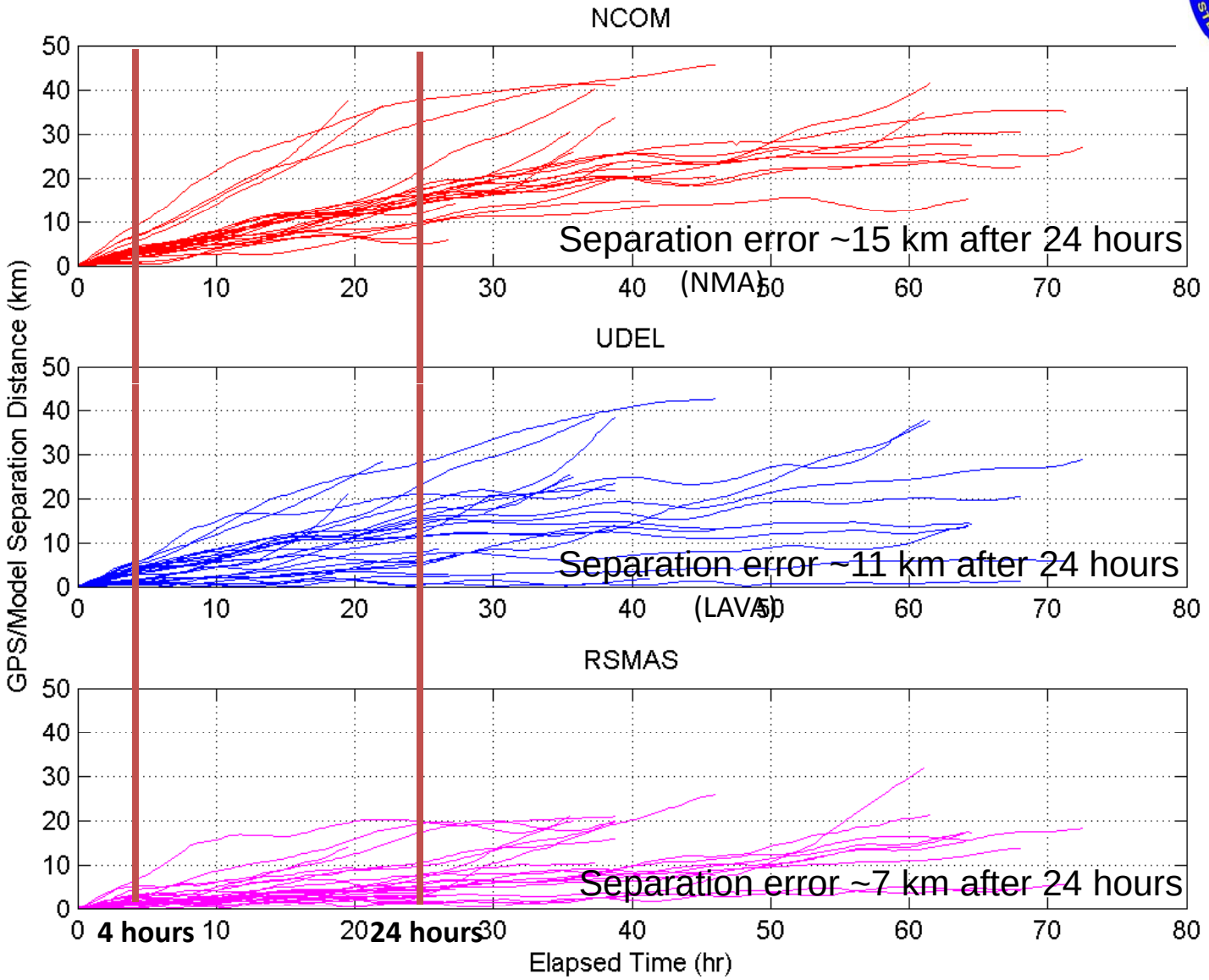


Green - NMA Predicted drift after blending In the buoy GPS data

24 hour RMS drift error reduced from 15 km to ~11 km

Chang et al., (accepted)

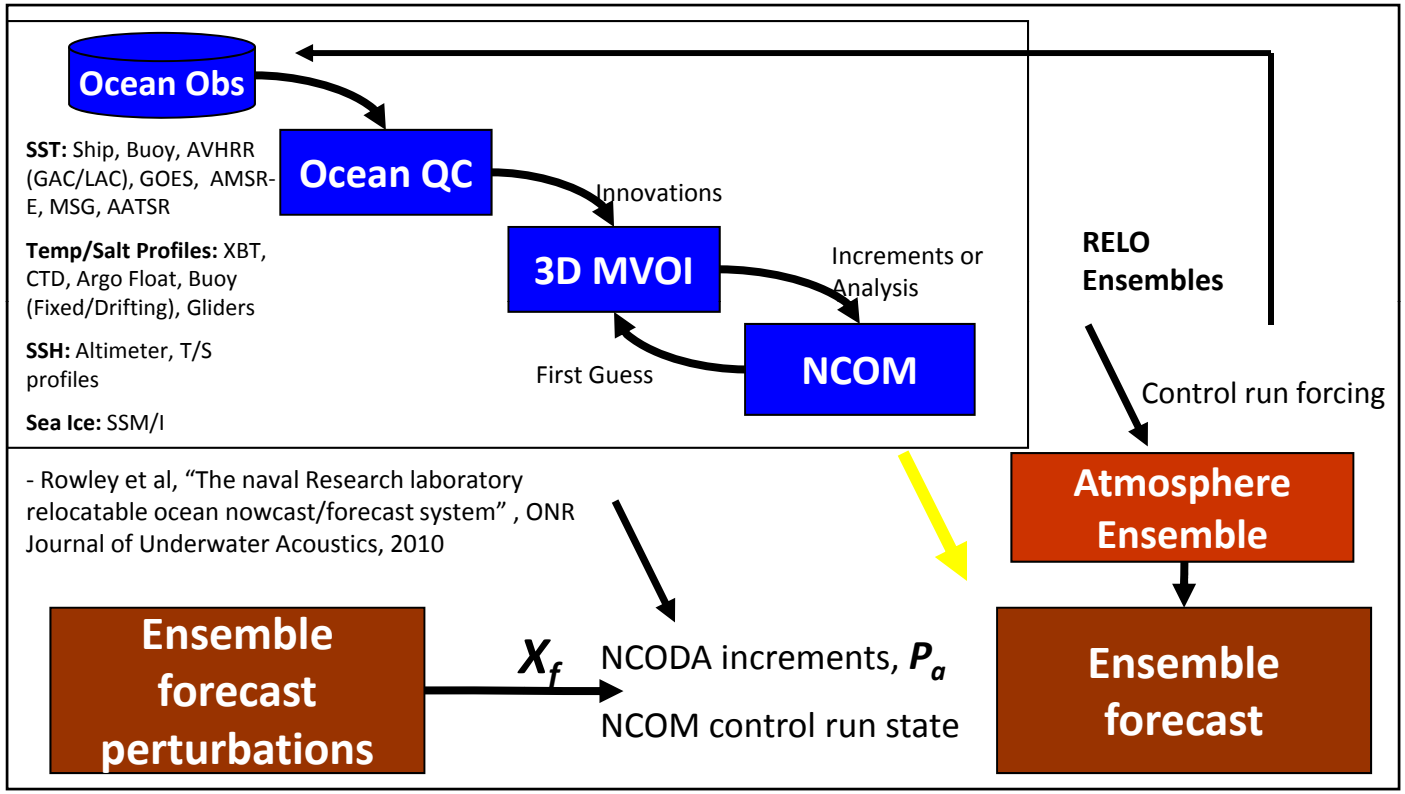
Time History of Separation Distance



All are "beating" the threshold, but none beating the goal

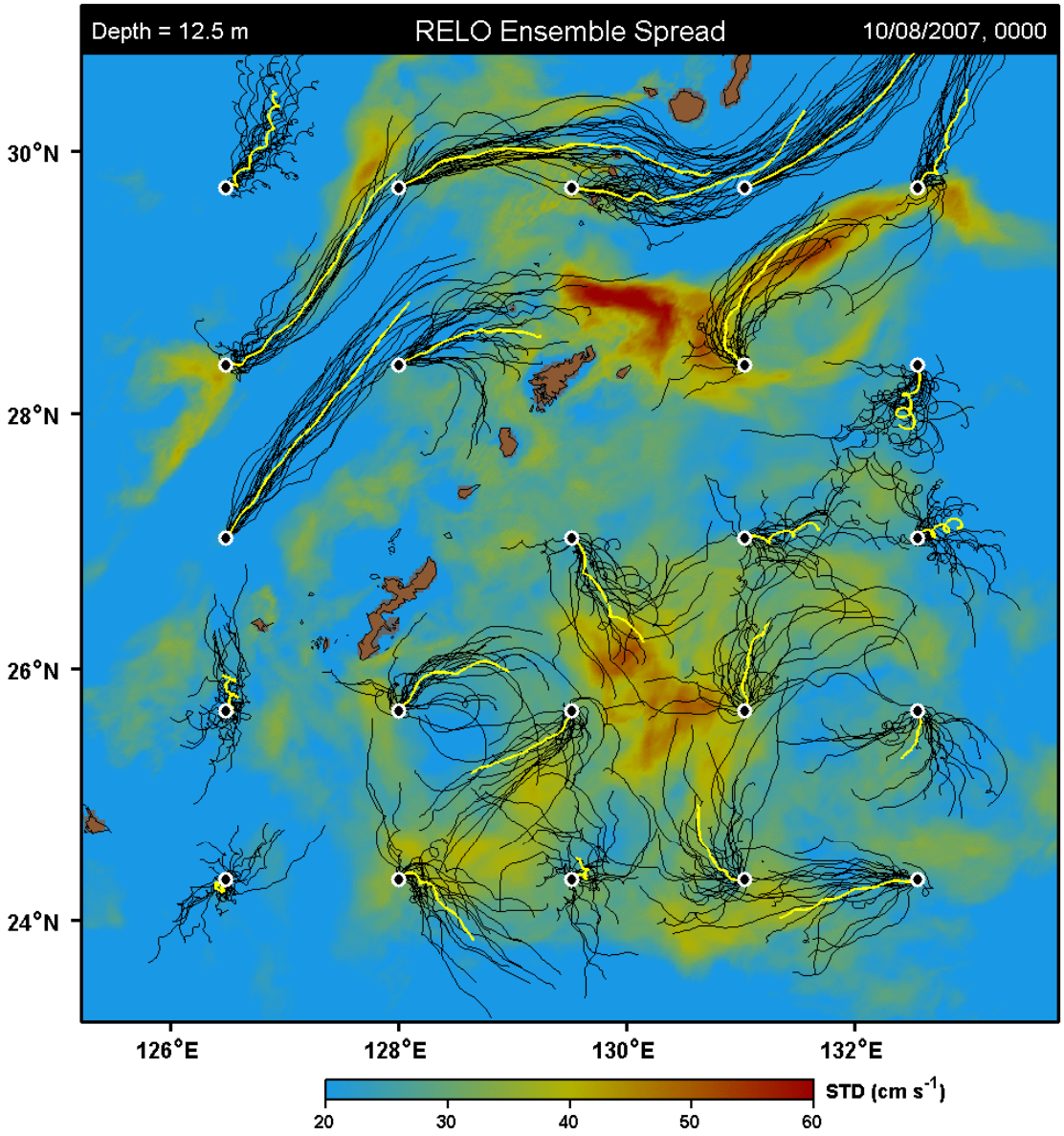
Chang et al., (accepted)

Ensemble Approach to Quantifying Ocean Uncertainty



Ensemble Transform Kalman Filter (ETKF) – Bishop and Tooth (1999)

NCOM ensembles during LWAD07-2 Oct. 8-20 2007



24 members, 72 hour forecast, yellow=mean trajectory, background variance of speed

OPERATIONAL IMPLEMENTATION

SELECT INPUT PARAMETERS:

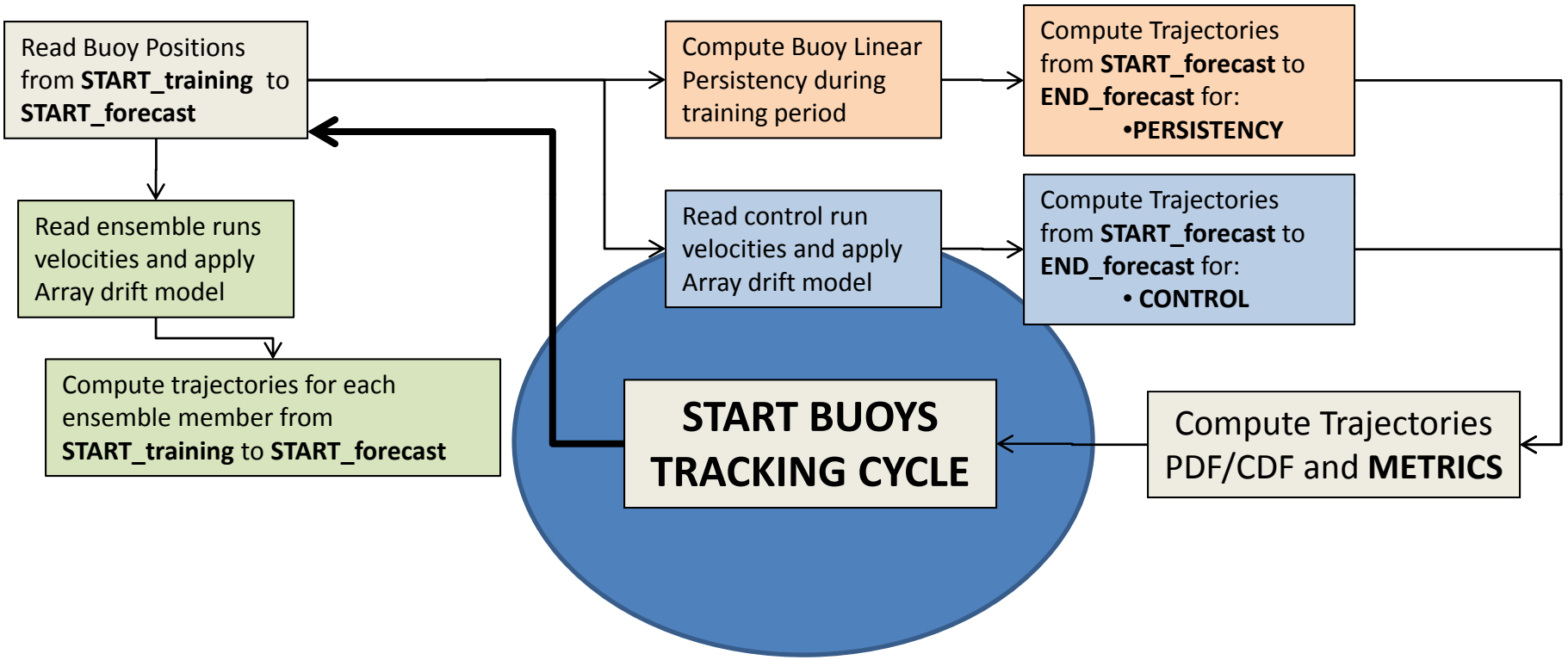
a) Levels to use in array aspect ratios;

b) Length for training and forecast

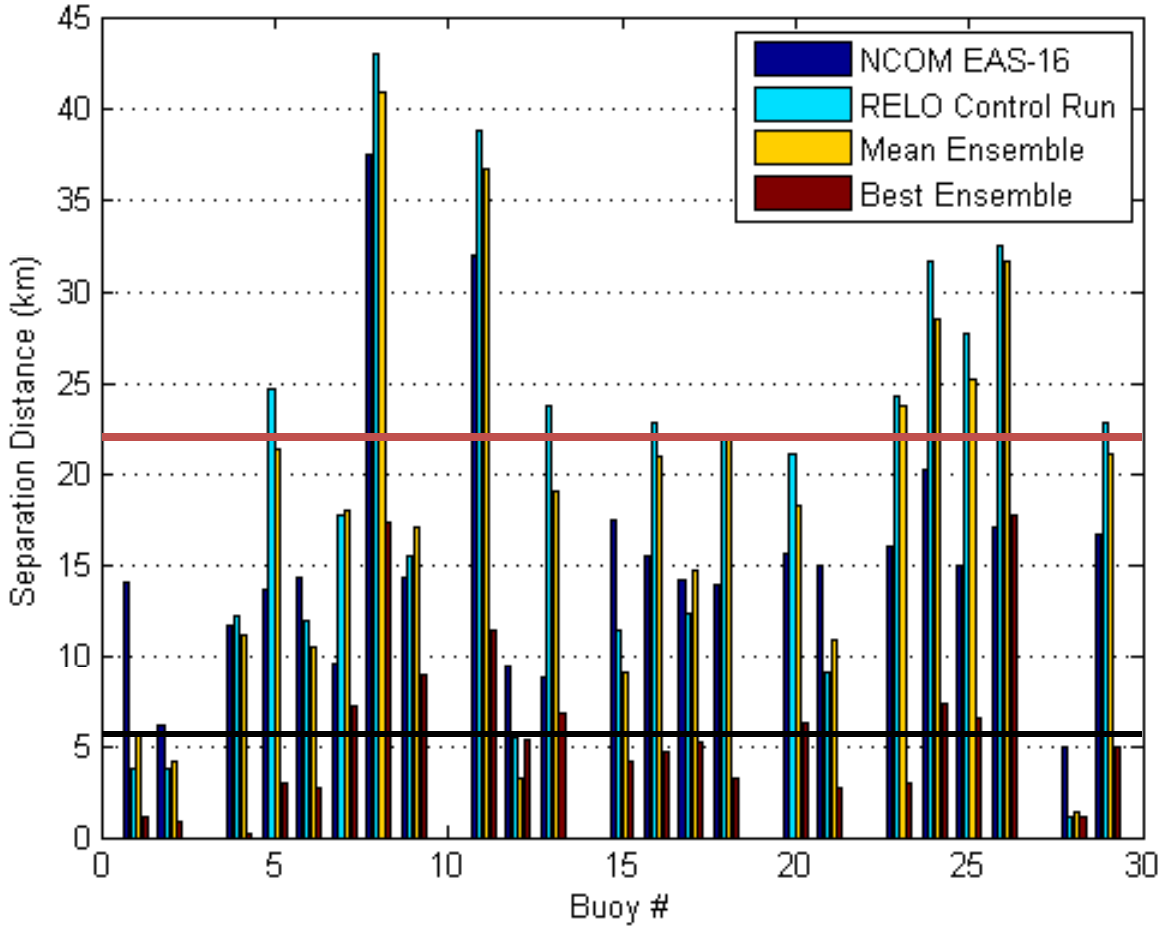
c) Array drift models

d) Directories/filenames with model and GPS data

e) Number of time-steps and grid points to use in augmented ensemble population



Separation distance at 24 hours



22 km/24 hours threshold

5.6 km/24 hours goal

Threshold: +/- 3.7 km/4 hours (+/- 22.2 km/24 hours)

Most meet the threshold separation (but there are outliers), few meet the goal

OPERATIONAL IMPLEMENTATION

SELECT INPUT PARAMETERS:

a) Levels to use in array aspect ratios;

b) Length for training and forecast

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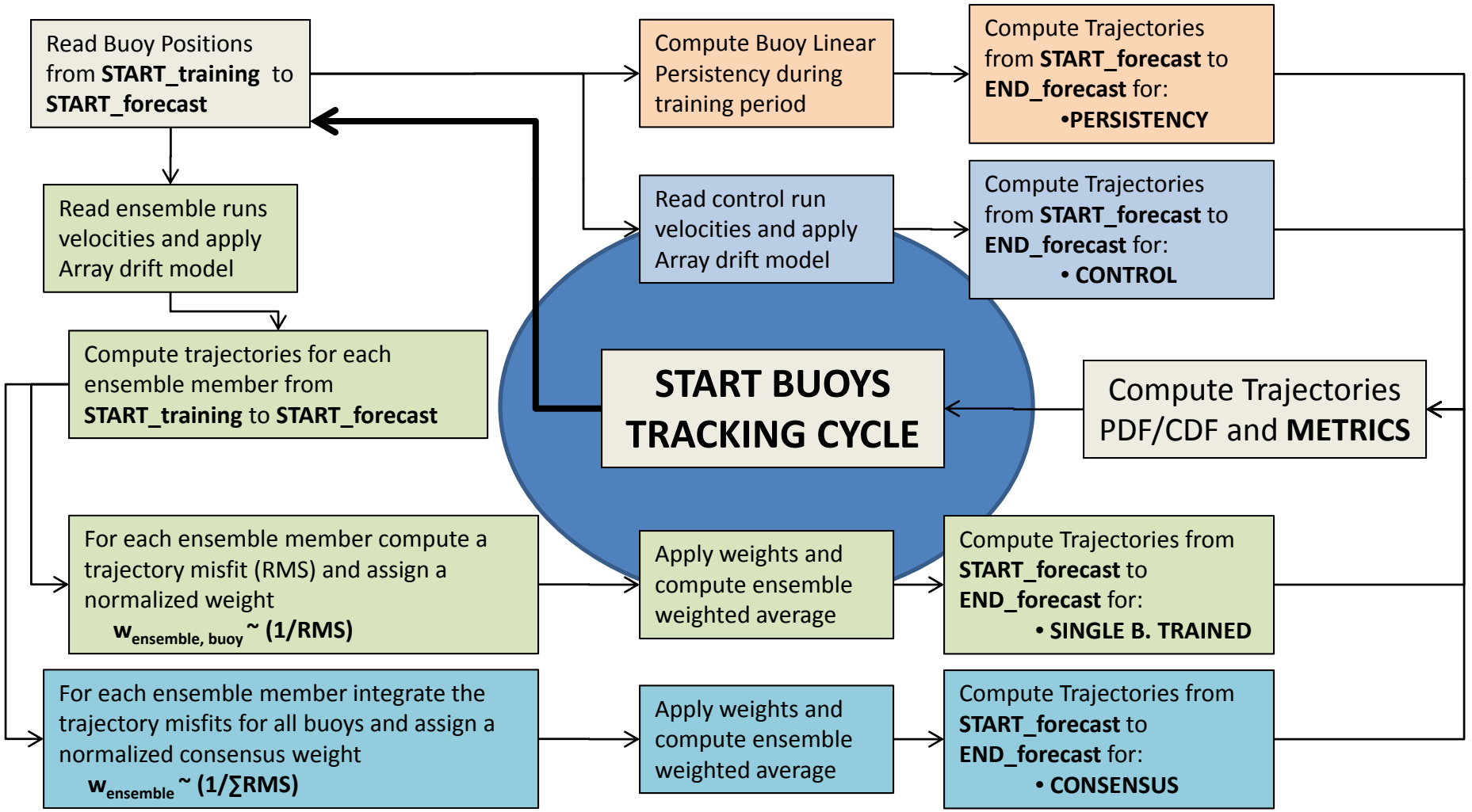
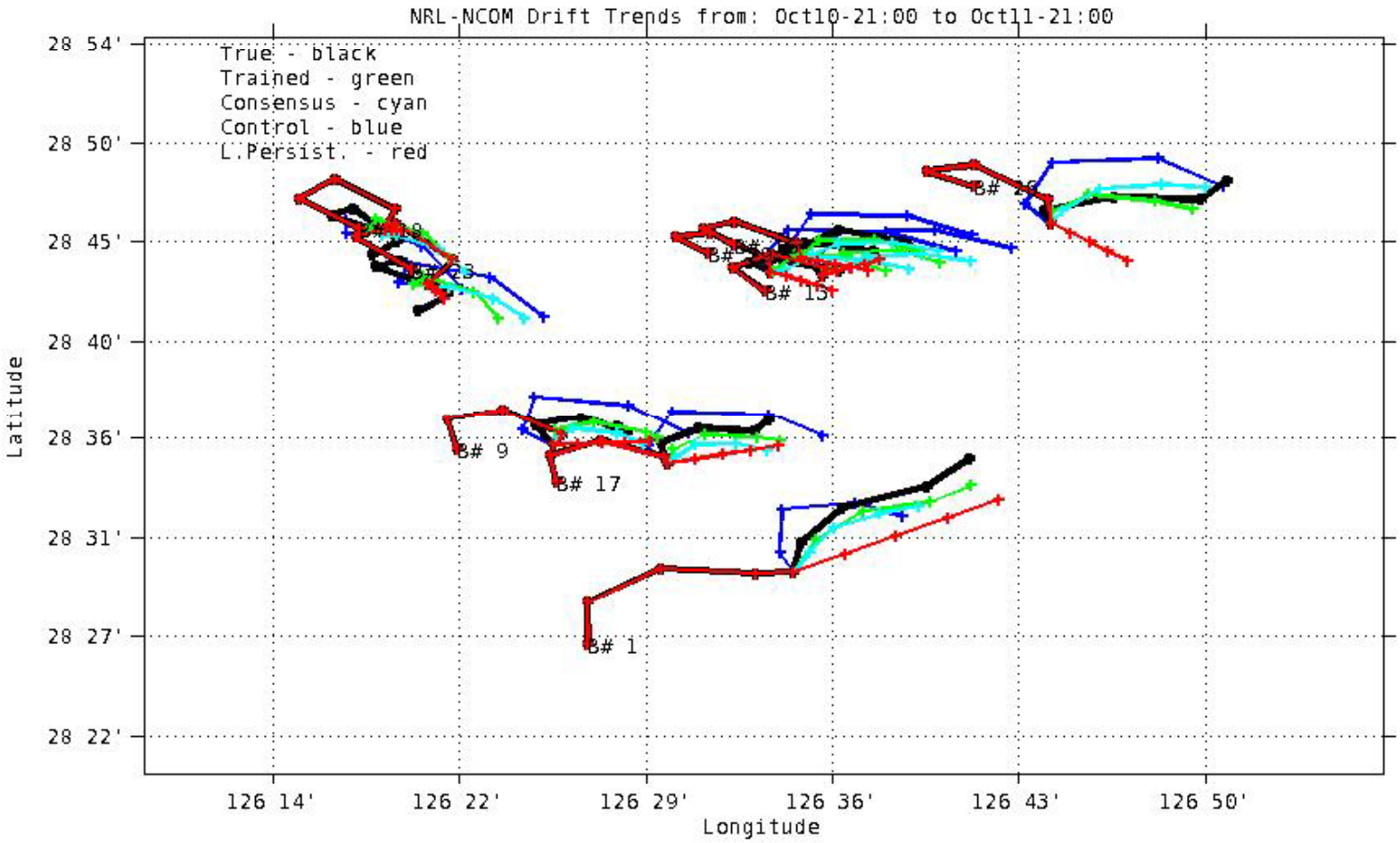
d) Directories/filenames with model and GPS data

e) Number of time-steps and grid points to use in augmented ensemble population



Re-Analysis Tracking Example (run Oct 10)

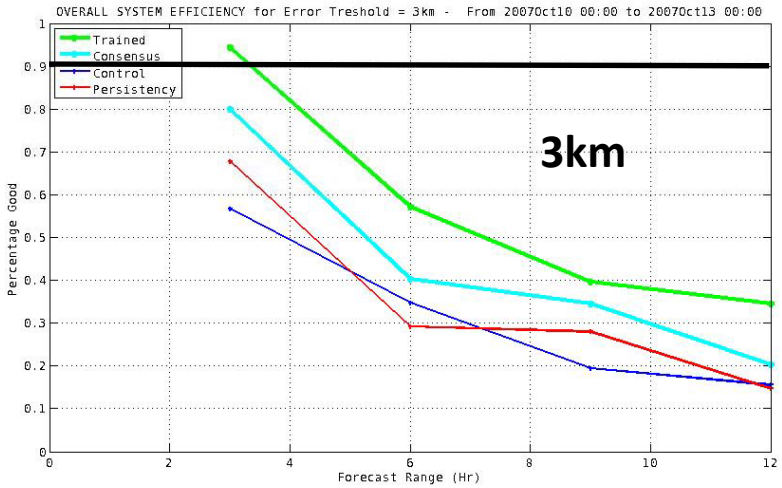
Using 12 hours training for 12 hours forecast



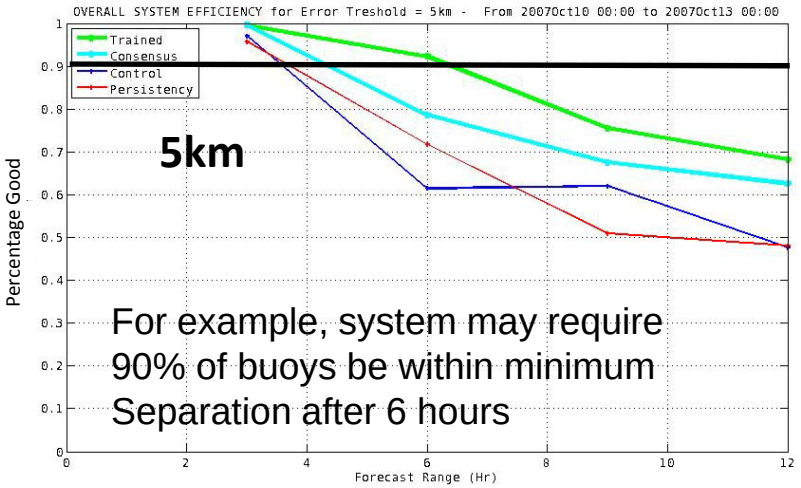
Tracking Examples (run Oct 10)

Efficiency defined as :

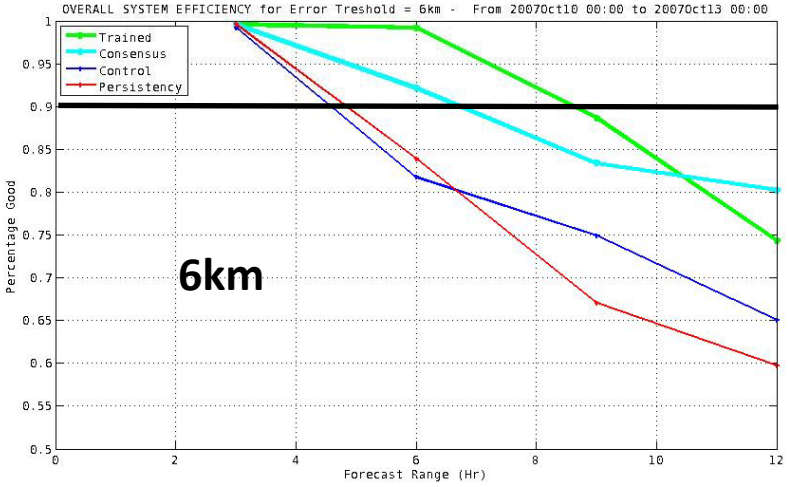
Number of cases with error below a threshold over the total number of observed errors



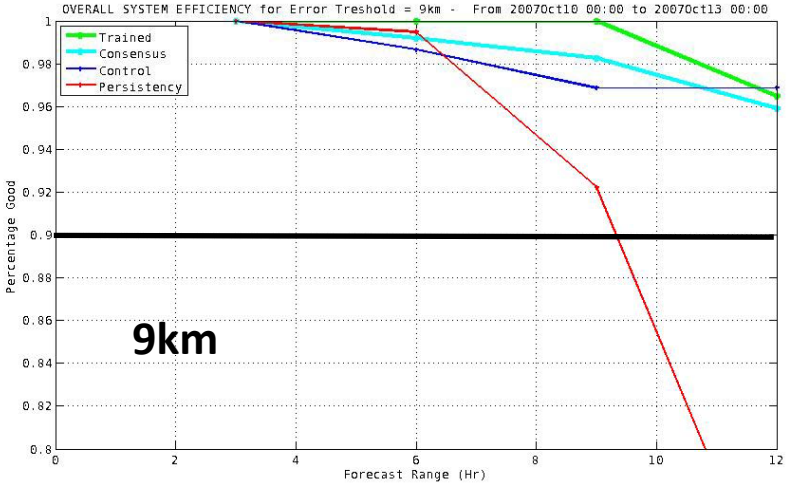
90%



For example, system may require 90% of buoys be within minimum Separation after 6 hours

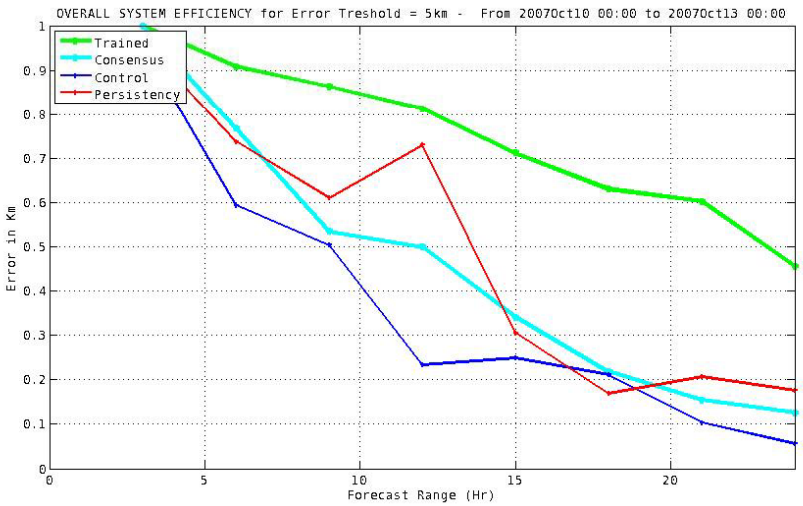


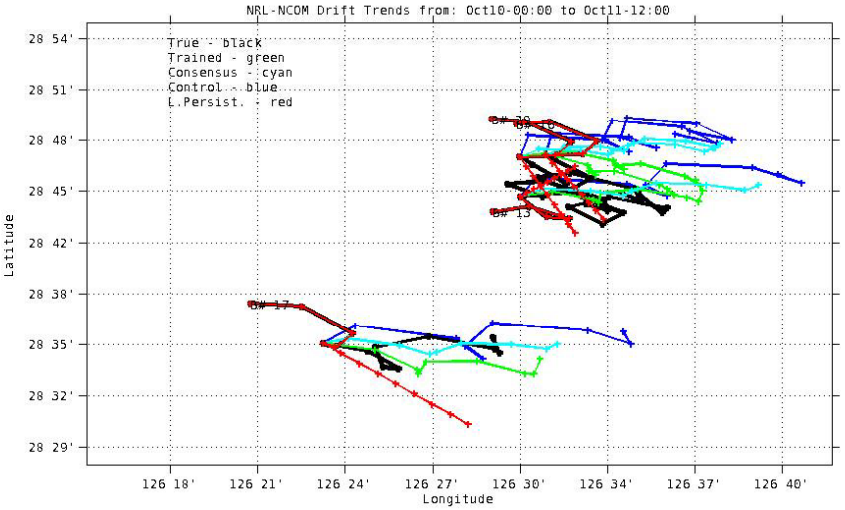
90%



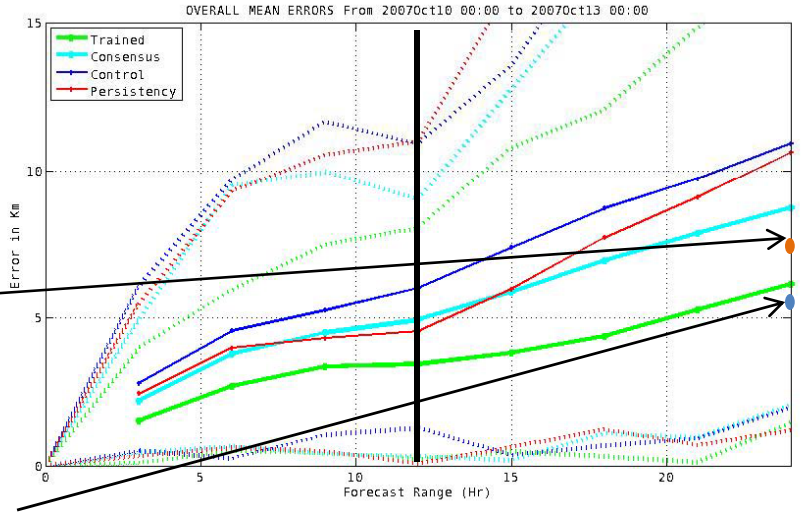
Re-analysis Tracking extended for 24 hours forecasts (Oct 10)

Using 12 hours training for 24 hours forecast





% of Bouys meeting *goal*
(actually 5.0 km) after 24 hours



LAVA Analysis mean separation error after 24 hours (7.1km) as reported in Chang, et al. "Enhanced Estimation of Sonobuoy Trajectories by Velocity Resconstructions", Ocean Modeling, 2010

BEST ENSEMBLE mean separation error after 24 hours (5.7km) as reported in Pat Hogan brief, PAADS/ISEC ONR-FNC Program Review, Feb 2010

For the mean sep. error, , trained and "best" very close!

Summary and Conclusions

Investigated different methods of reducing observed
And forecasted sonobuoy separation errors

	24 hr. Sep. Error	Threshold Error 24 hrs	Goal Error 24 hrs
EAS16	15 km	22.2 km	5.6 km
NMA/UDEL	11 km	22.2 km	5.6 km
LAVA/RSMAS	7 km	22.2 km	5.6 km
Ens-Control	11 km	22.2 km	5.6 km
Ens-Perst.	11 km	22.2 km	5.6 km
Ens-Mean	10 km	22.2 km	5.6 km
Ens-Best	6 km	22.2 km	5.6 km
Ens-Consens.	8 km	22.2 km	5.6 km
Ens-Trained	6 km	22.2 km	5.6 km

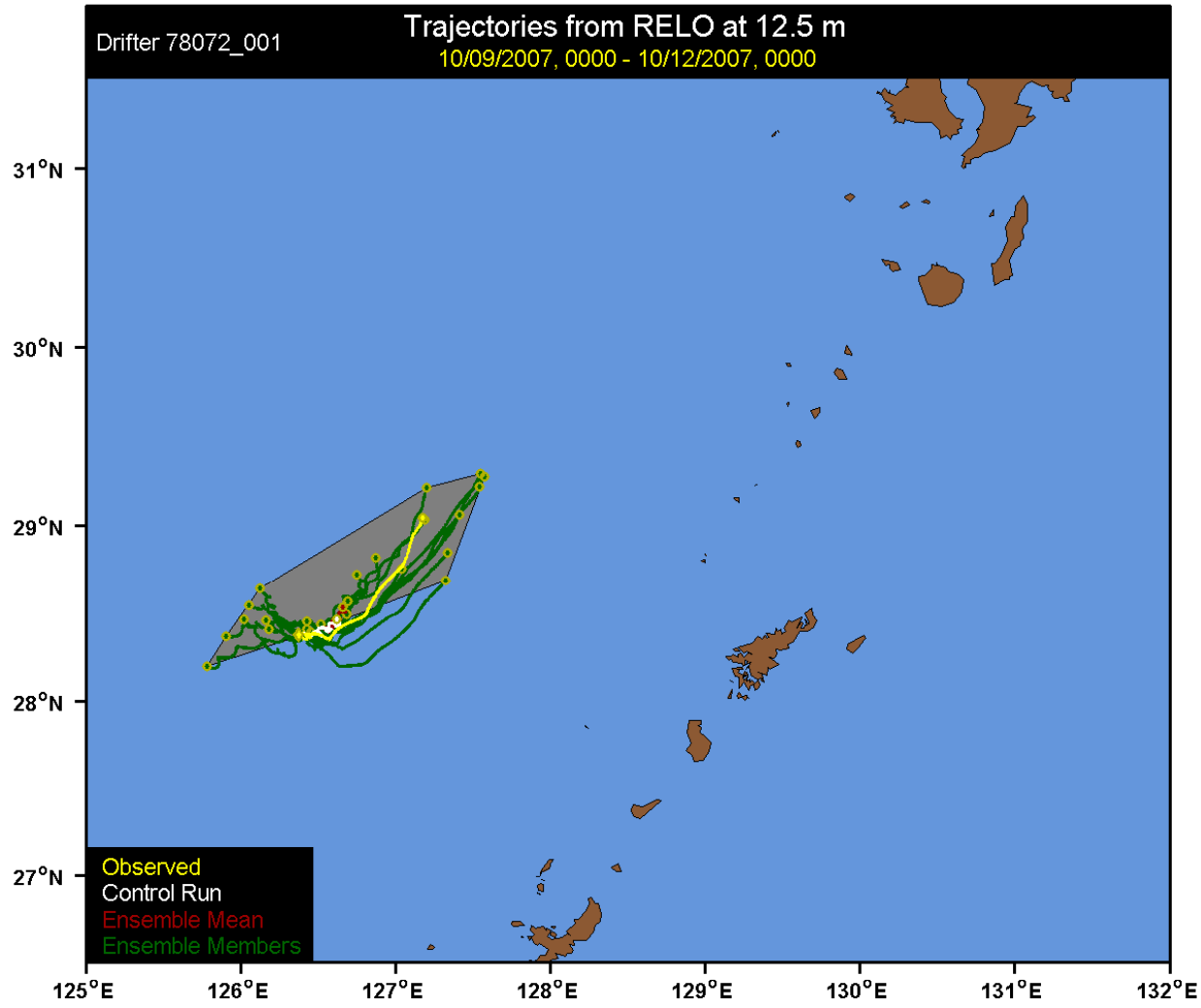
Challenging problem, Eularian Model expected to reproduce
(and forecast) Lagrangian characteristics

Questions?

RELO Ensemble Performance Assessment

Does ensemble capture uncertainty?

Observed and simulated drifter tracks from the LWAD07 experiment show that the ensemble spread does not always contain the observed drifter track.



Observed (yellow), RELO NCOM simulated (white), and RELO ensemble mean (red) and individual (green) drifter tracks for 3-day forecasts during the LWAD07 drifter deployment (09-12 Oct 2007).

Bruce Lipphardt, UDel

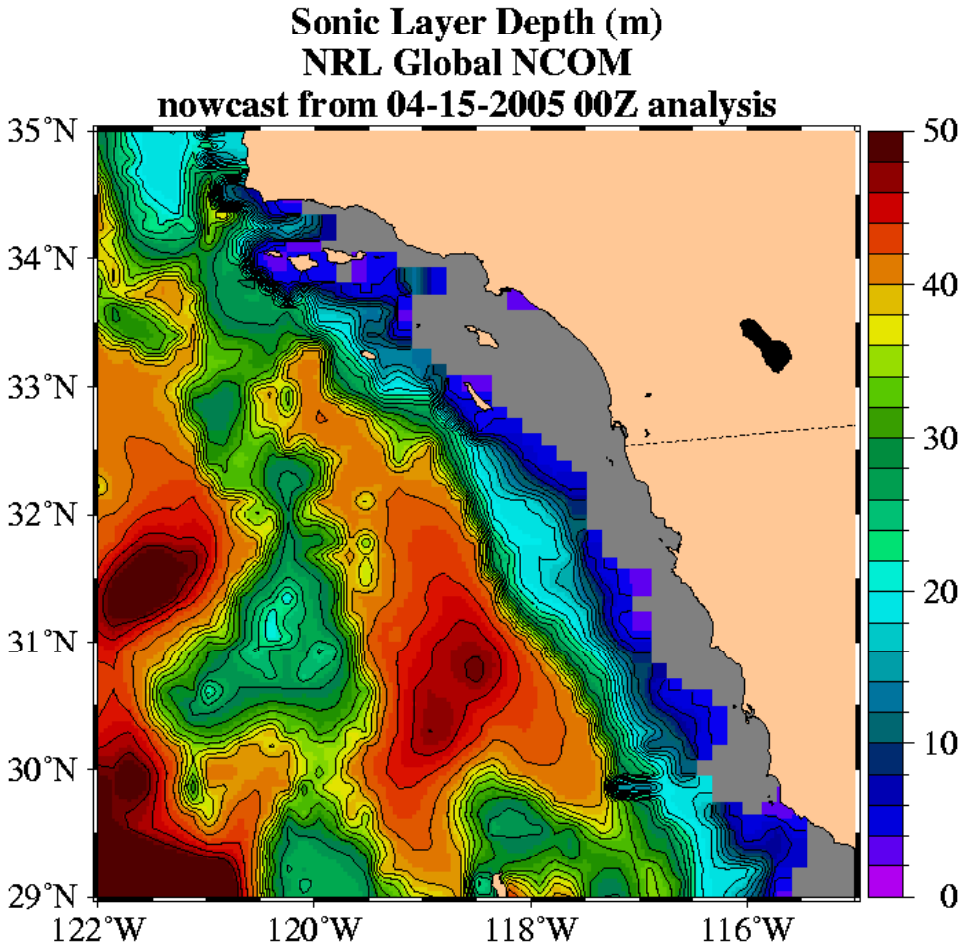
Sonobuoy Drift Builds on Forecast Applications

Navy METOC Operational Oceanography areas and ocean environment that must be predicted, anywhere, anytime

Ocean Environment

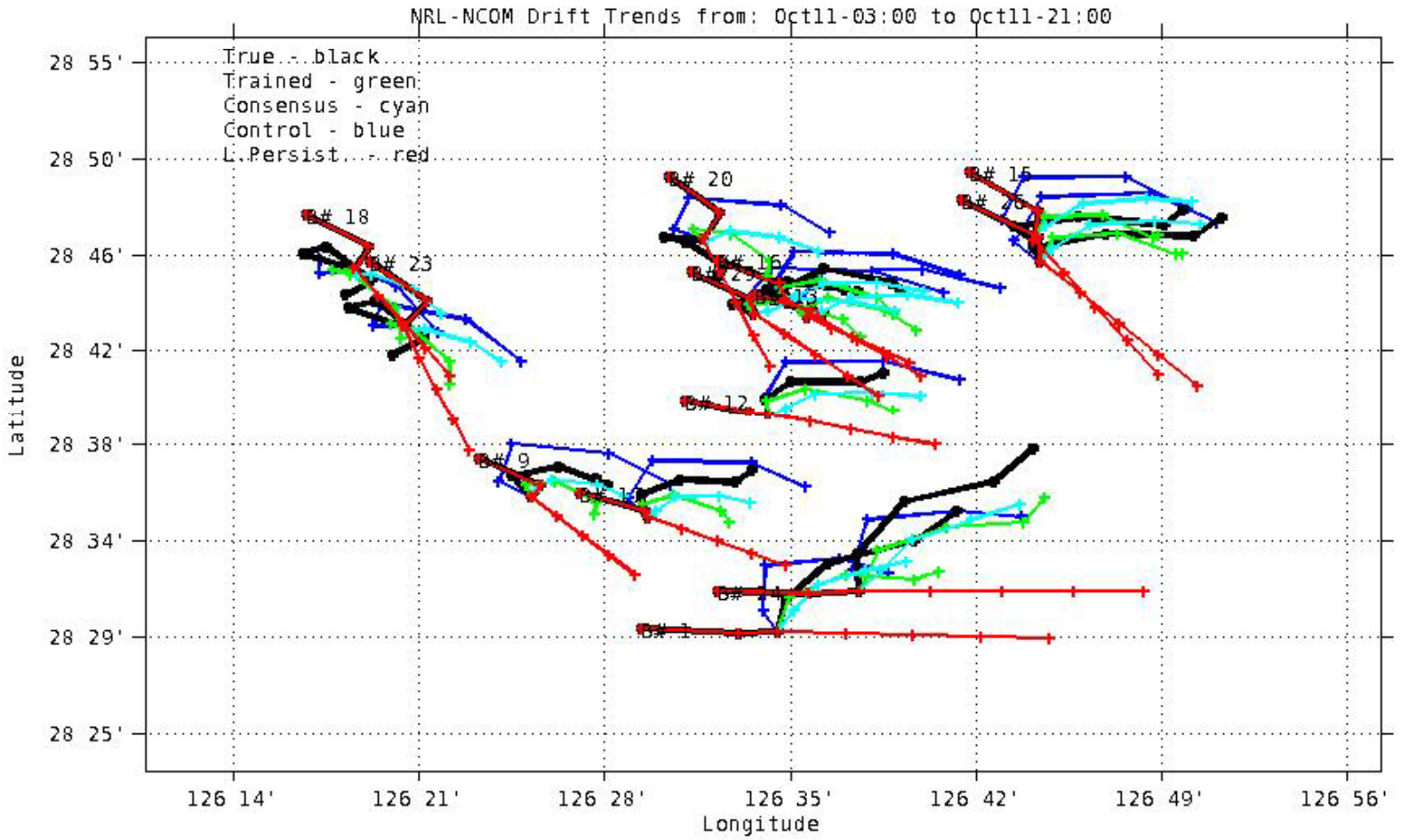
Operational Oceanography warfare areas

	Currents	Temperature / Salinity / Sound Velocity Profile	Surface Waves	Ice
ASW	Sonobuoy array drift and dispersion	Acoustic propagation and detection	Noise generation through wave breaking	Acoustic propagation
NSW	Swimmer / SDV	Water temperatures Density	Rib boat / LCAC operational parameters	
MIW	Mine drift	Acoustic propagation	Mine burial	
ISR	Sensor/UUV drift			
PTA				
Fleet Ops	STOM		STOM	
Nav	Optimal Ship Track Routing		Optimal Ship Track Routing	
Aviation		Atmospheric prediction		
Mar Ops	At Sea Resupply		At Sea Resupply	Navigation hazards



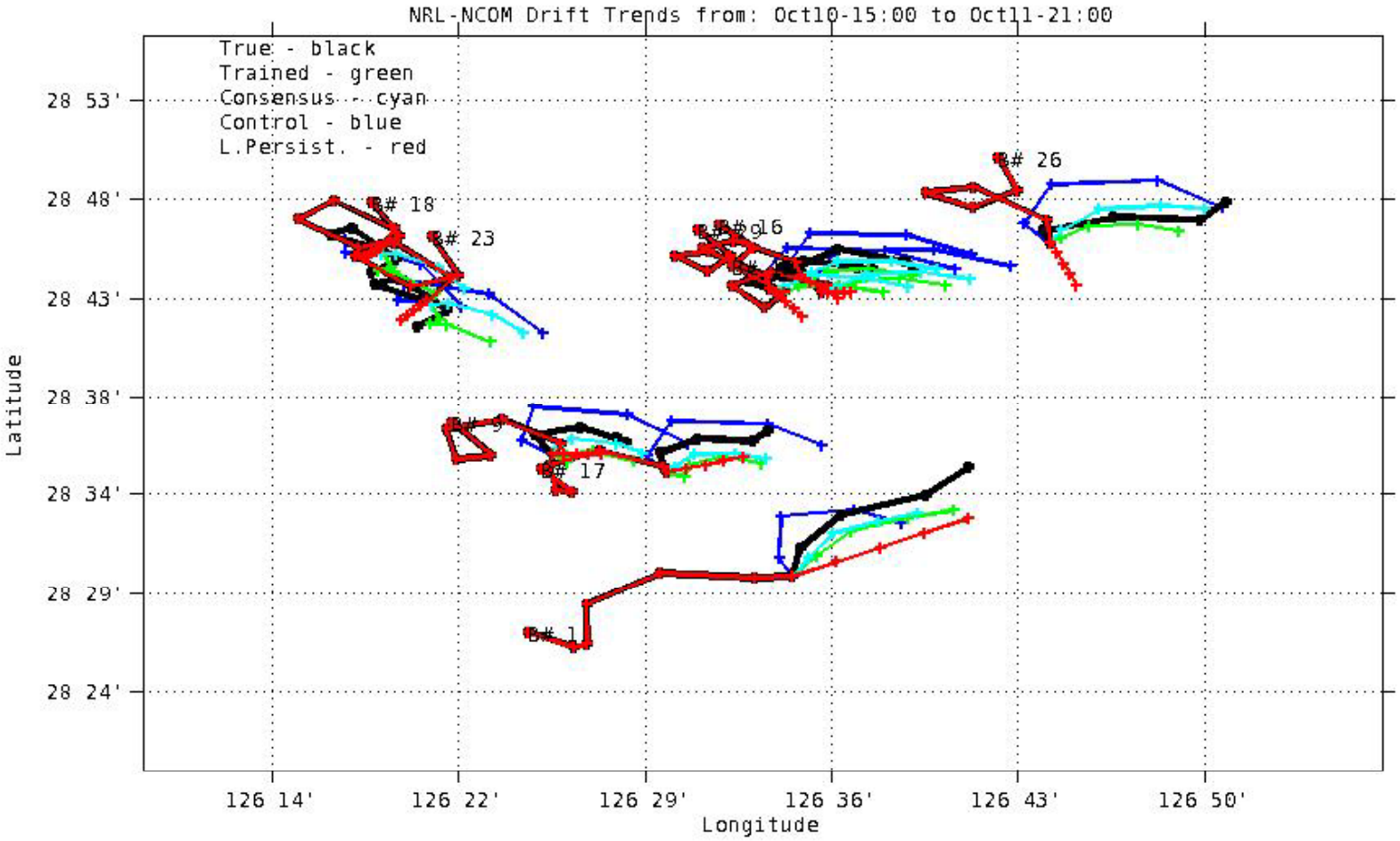
Tracking Examples (run Oct 10)

Using 6 hours training for 12 hours forecast

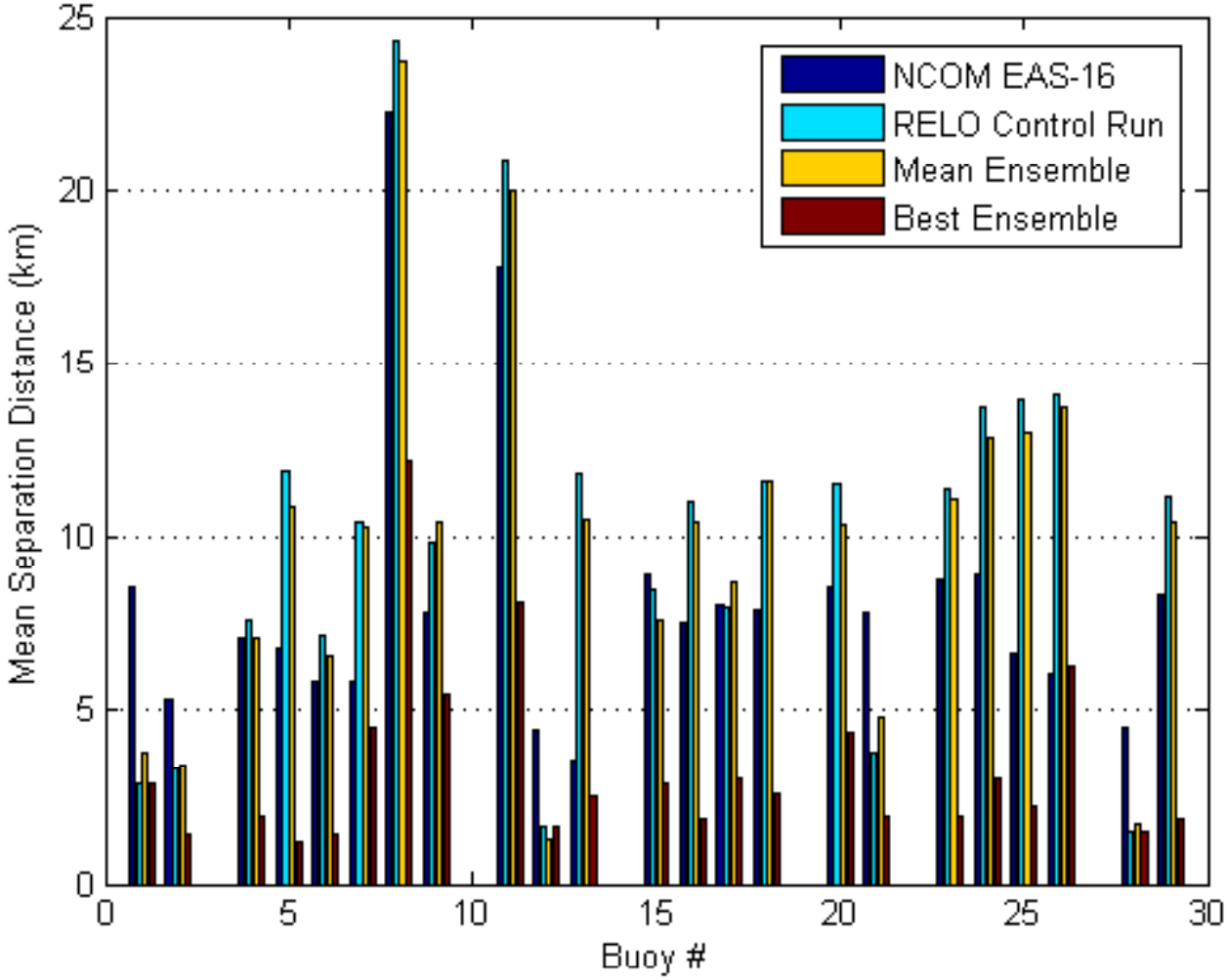


Tracking Example (run Oct 10)

Using 18 hours training for 12 hours forecast



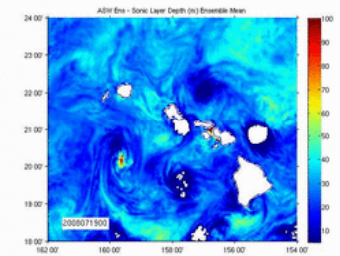
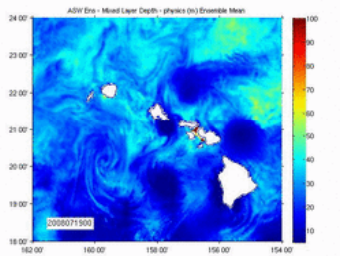
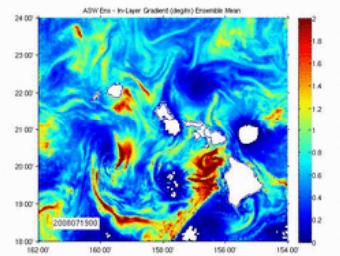
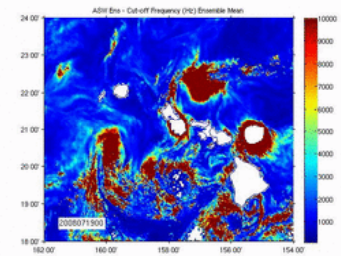
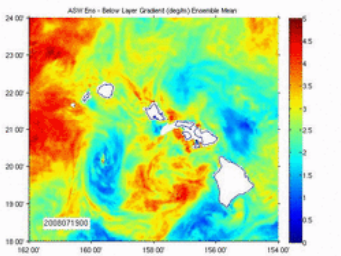
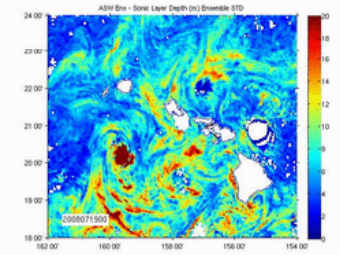
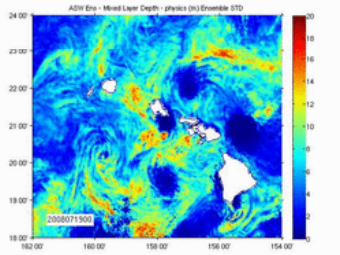
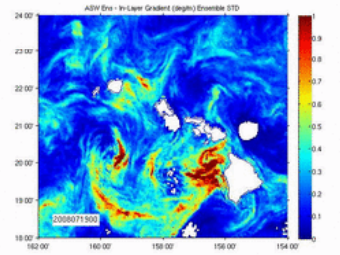
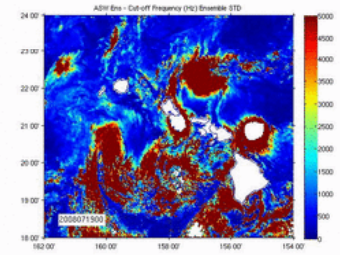
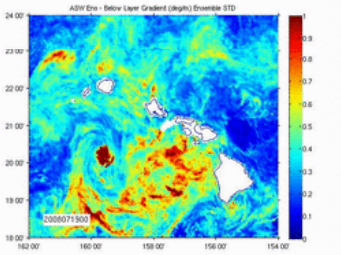
Mean Separation distance over 24 hours



Mean separation over 24 hours smaller than separation after 24 hours
But this is the mean path, SHOULDN'T THIS BE MORE MEANINGFUL?

Acoustic Variable Ensemble Estimates

Surface acoustic parameters

	SONIC LAYER DEPTH	MIXED LAYER DEPTH	IN-LAYER GRADIENT	CUT-OFF FREQUENCY	BELOW LAYER GRADIENT
ENSEMBLE MEAN					
ENSEMBLE STD					

PAADS: ensemble spread can be used to predict trajectory uncertainty

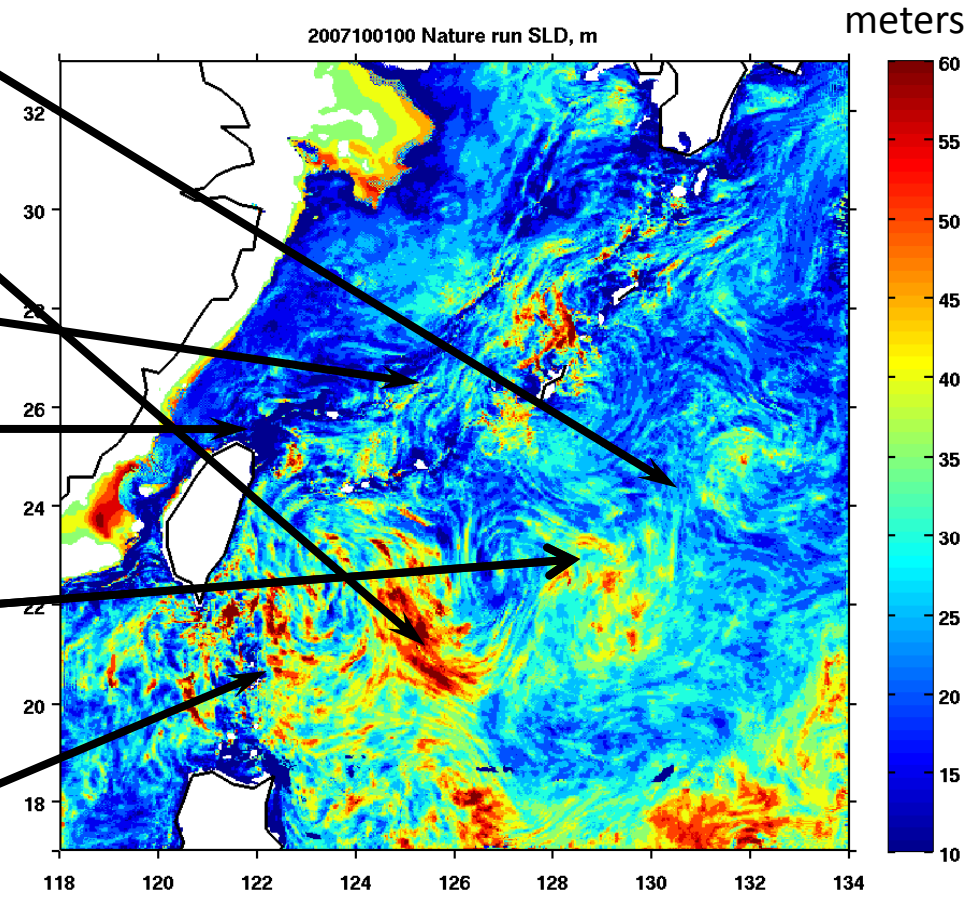
NRL adaptive sampling: Where to deploy observational assets to reduce ensemble spread, also to pass uncertainty to acoustic TDA's.

E . Coelho/NRL

Forecasts of the environment for acoustic propagation

- Diurnal variability apparent in SLD, particularly in shallow SLD areas
- Typhoon events create short-lived shallowing and deepening
- Deeper SLD associated with Kuroshio flow to the northeast
- Upwelling northeast of Taiwan results in persistent shallow SLD
- Mesoscale features result in large scale modulation of SLD (large area deepening or shallowing depending on cold core or warm core eddy)
- Internal tides radiating from Luzon Strait create wave fronts in SLD, which may interact depending on depth of sonic layer and depth of internal waves

October 2007; 3 hour frames
Sonic Layer Depth (SLD)
from 3 km regional NCOM



Specific flow features correlate with sound speed and impact acoustic performance surfaces.