Methodology and Architecture for Using Oceanographic and Meteorological Ensembles to Improve Forecast Skill and Guidance in Support of Tactical Planning and Operations

James Etro[1], John Cook[2], Arthur Etro[1], and James Hansen[2]

(1) Itri Corporation, Springfield, VA, USA

(2) Naval Research Laboratory, Monterey, CA, USA

jim.etro@itricorp.com

Sponsored by ONR (Phase II STTR Contract N00014-08-C-0173)

Outline

- Motivation
- Background
- Systems
- Results
- Conclusions
- Future Work

Motivation

- Decision makers and operators must make complex plans and decisions ad-hoc and often go into action on short notice
  - Must process a large amount of information quickly
  - Only able to use what is at hand and easily understood

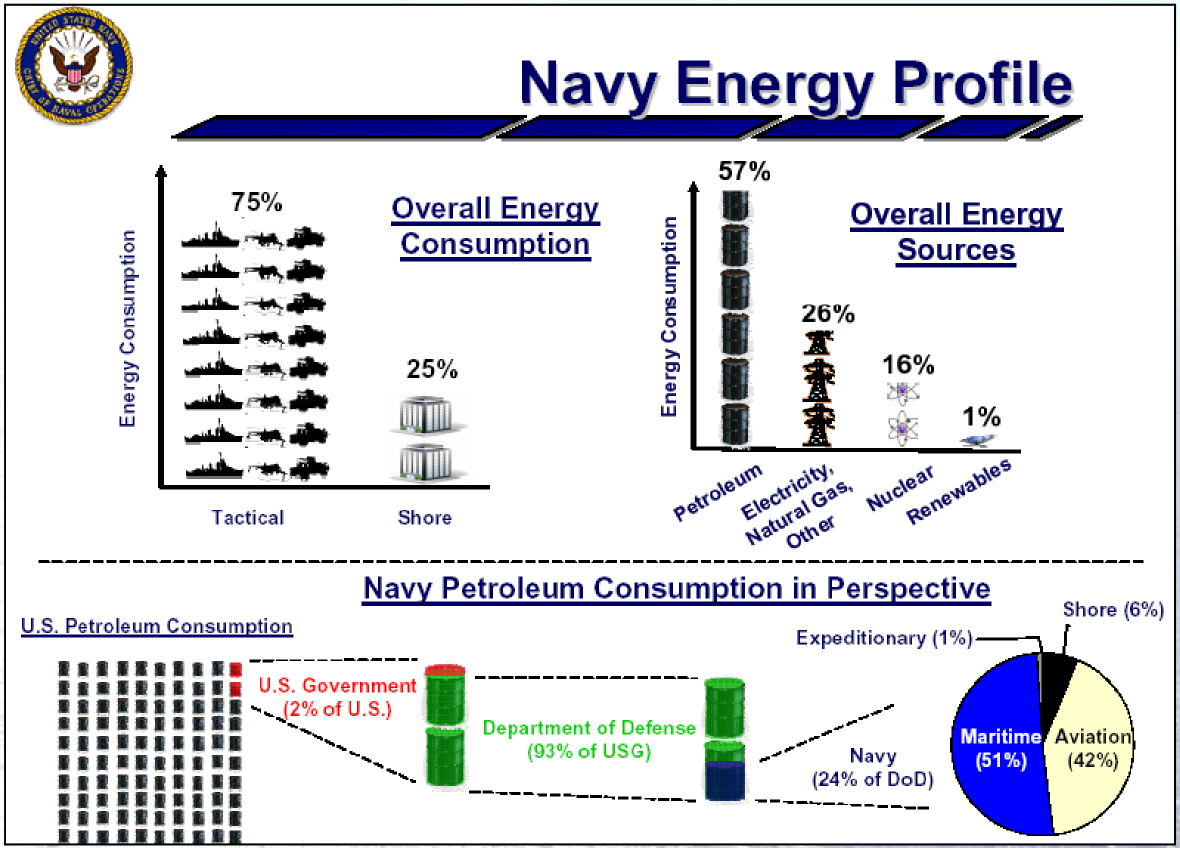
- METOC ensembles can be an important source of information for the decision maker; however, they:
  - Provide ambiguous and redundant information
  - Are difficult to interpret and apply directly

The value that ensemble prediction brings to problem solving is easily overlooked if the information isn't in a form that makes it immediately understandable and actionable

Goal: Derive a consensus forecast from ensemble data to improve an existing US Navy ship routing application

Need for Smart Ship Routing

- **FY2007 Defense Authorization Act Section 360** makes it Department of Defense (DOD) policy to <u>improve the fuel efficiency</u> of weapons platforms, consistent with mission requirements, and requires a report on DOD progress in implementing the policy



Navy - FY08: ~35 M bbls
Transit Estimate ~11 M bbls

Background

Results from previous work

- **Simple bias correction worked well for most parameters to improve the ensemble mean**
- **At longer forecast times, gradients in the ensemble means are too weak**
- **Simple techniques for PDF spread adjustment did not add value**
- **For short duration forecasts (24 to 72h), training data sets of as little as 25 days are adequate for reducing model bias**

Parameter	Tau	Best Ensemble Average Conditioning Method Compared to Analysis	Error Compared to Analysis		
			Ave Error		Improvement
			Analysis – Ensemble	Analysis – Ensemble Mean	
Sig Wave Hgt	06	Bias Correction	.222	.164	.058 M
	24	Bias Correction	.243	.174	.069 M
	48	Bias Correction	.313	.230	.083 M
SFC Wind Speed	06	Bias Correction	1.04	.64	.4 m/s
	24	Bias Correction	1.38	1.0	.38 m/s
	48	Bias Correction	1.68	1.25	.43 m/s
SFC Wind Direction	06	Raw Ensemble	30	23	7^{o}
	24	Raw Ensemble	38	30	8^{o}
	48	Raw Ensemble	47	38	9^{o}

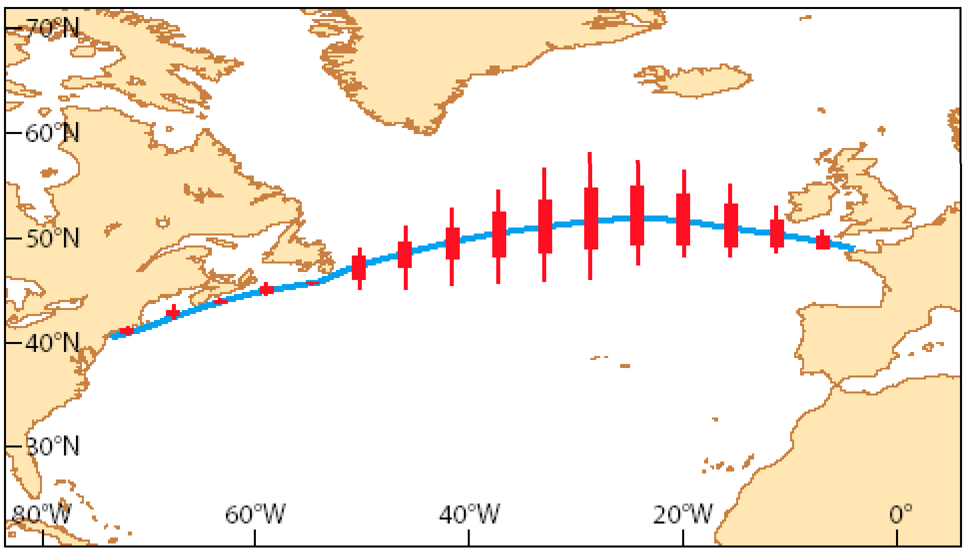
Consensus Forecasts for Smart Routing

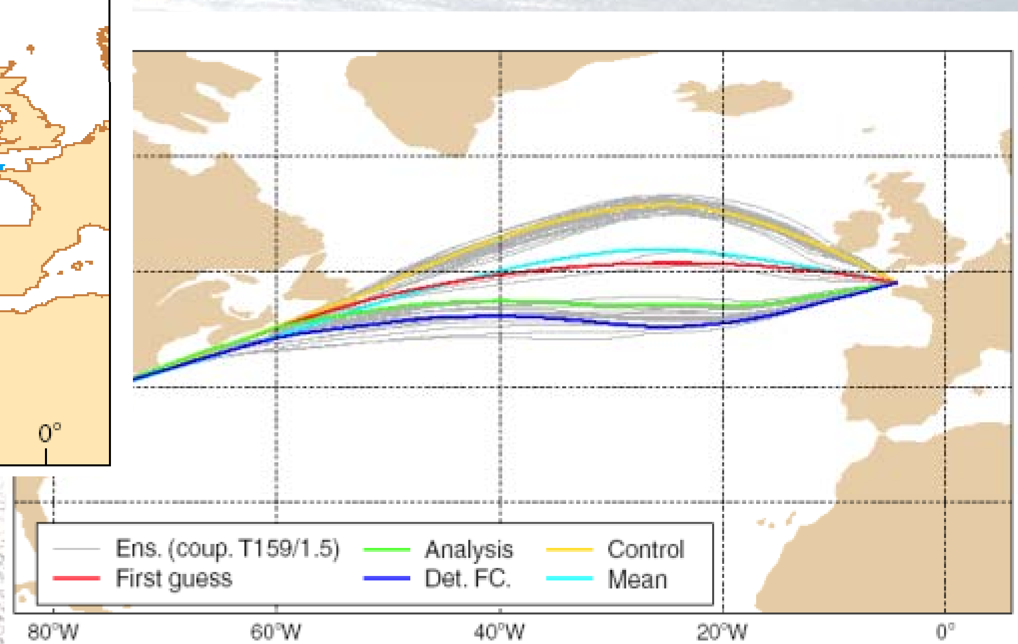
Post Processed Ensemble Forecast Improvement			
Needed Parameters	**24 Hr FCST**	**72 Hr FCST**	**144 Hr FCST**
SWL_WAVE_DIR	BIAS_CORR	RAW	RAW
SWL_WAVE_HT	BIAS_CORR	BIAS_CORR	BIAS_CORR
SWL_WAVE_PER	BIAS_CORR	BIAS_CORR	BIAS_CORR
WIND_DIR	RAW	RAW	RAW
WIND_SPD	BIAS_CORR	BIAS_CORR	RAW
WIND_WAVE_DIR	BIAS_CORR	BIAS_CORR	BIAS_CORR
WIND_WAVE_HT	BIAS_CORR	BIAS_CORR	BIAS_CORR
WIND_WAVE_PER	BIAS_CORR	BIAS_CORR	RAW

- **Developed Ensemble Forecast Application System (EFAS) software to provide ensemble post-processing of FNMOC operational fields**
- **Developed an interface for EFAS to Ocean Systems Inc. Ship Tracking and Routing System (STARS) algorithm used at FNMOC**
- **STARS also needs surface currents, SST, and climatology data**

STARS Ship Routing Engine

- Generates ship routes from voyage start/stop info, ship class, specified wind/sea limits (damage avoidance) for route and divert recommendations
- The Ship Route Engine finds the most efficient (least power) path, minimizing fuel burn, that also avoids land and bad weather
- Fuel burn along a specified route can also be computed





- Early approaches to supporting route decision making with ensemble information
- Which route to recommend?

EFAS Work Flow for Ship Routing

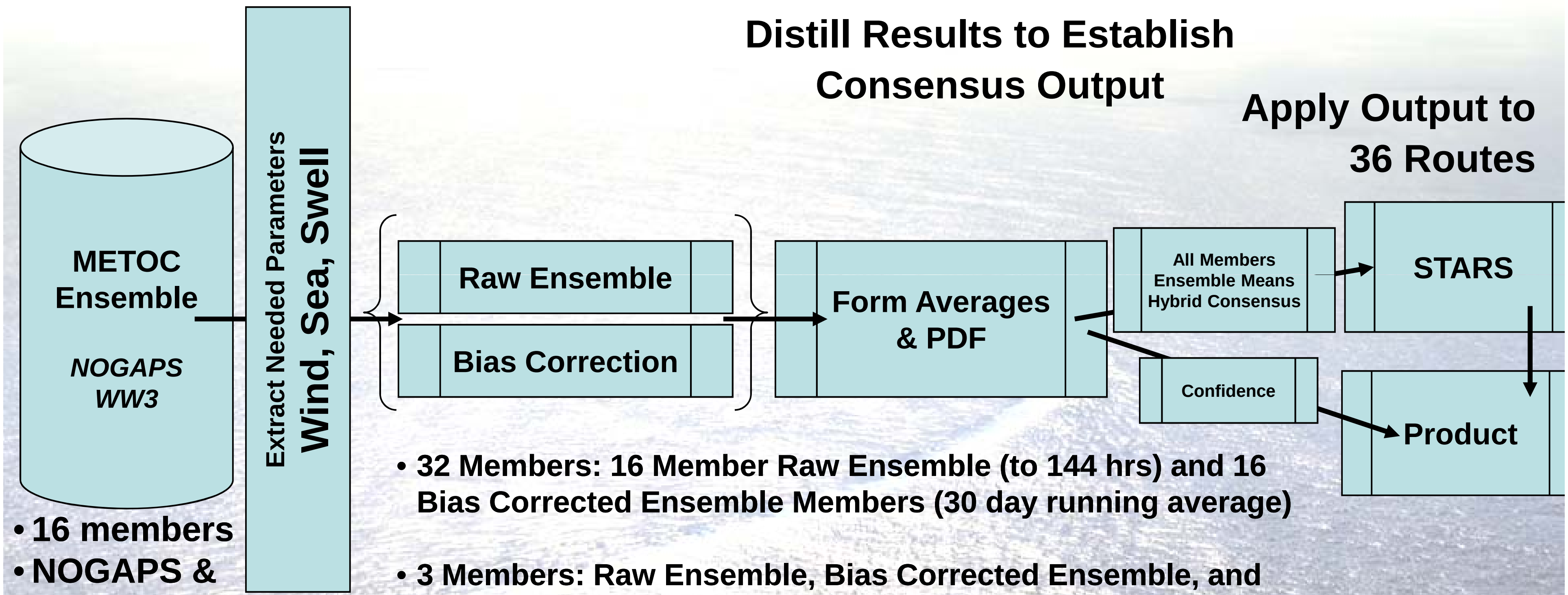
Ensemble Data

Determine Parameters Needed

Apply Calibration

Distill Results to Establish Consensus Output

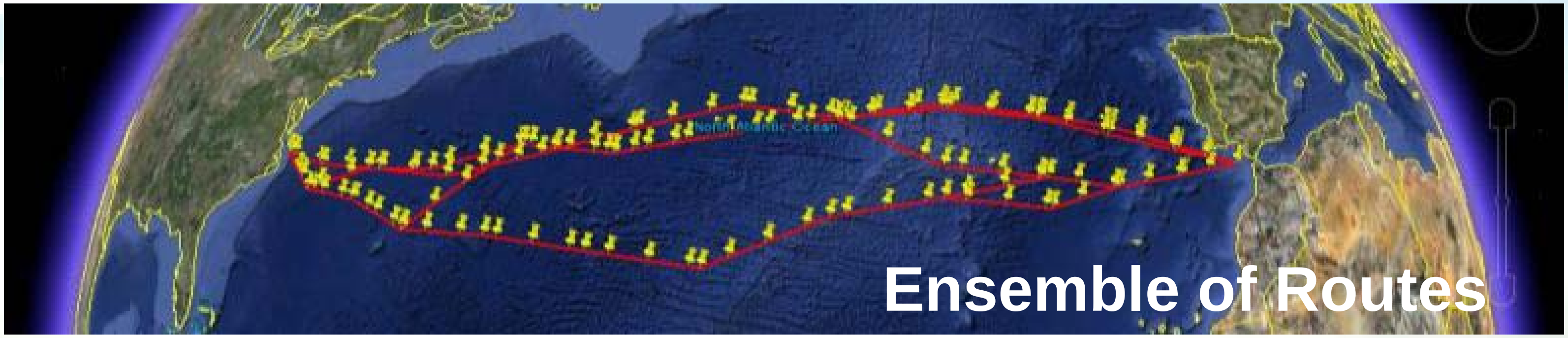
Apply Output to 36 Routes



- 16 members
- NOGAPS & WW3

- 32 Members: 16 Member Raw Ensemble (to 144 hrs) and 16 Bias Corrected Ensemble Members (30 day running average)
- 3 Members: Raw Ensemble, Bias Corrected Ensemble, and Hybrid Ensemble Averages
- Truth (Analysis)

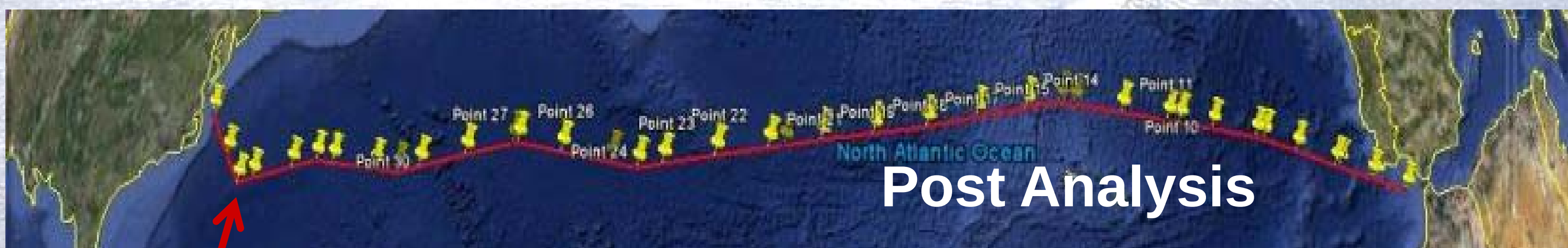
EFAS - STARS Route Recommendation



RAW Ensemble Horse Power
1532

BIAS CORR Horse Power
1530

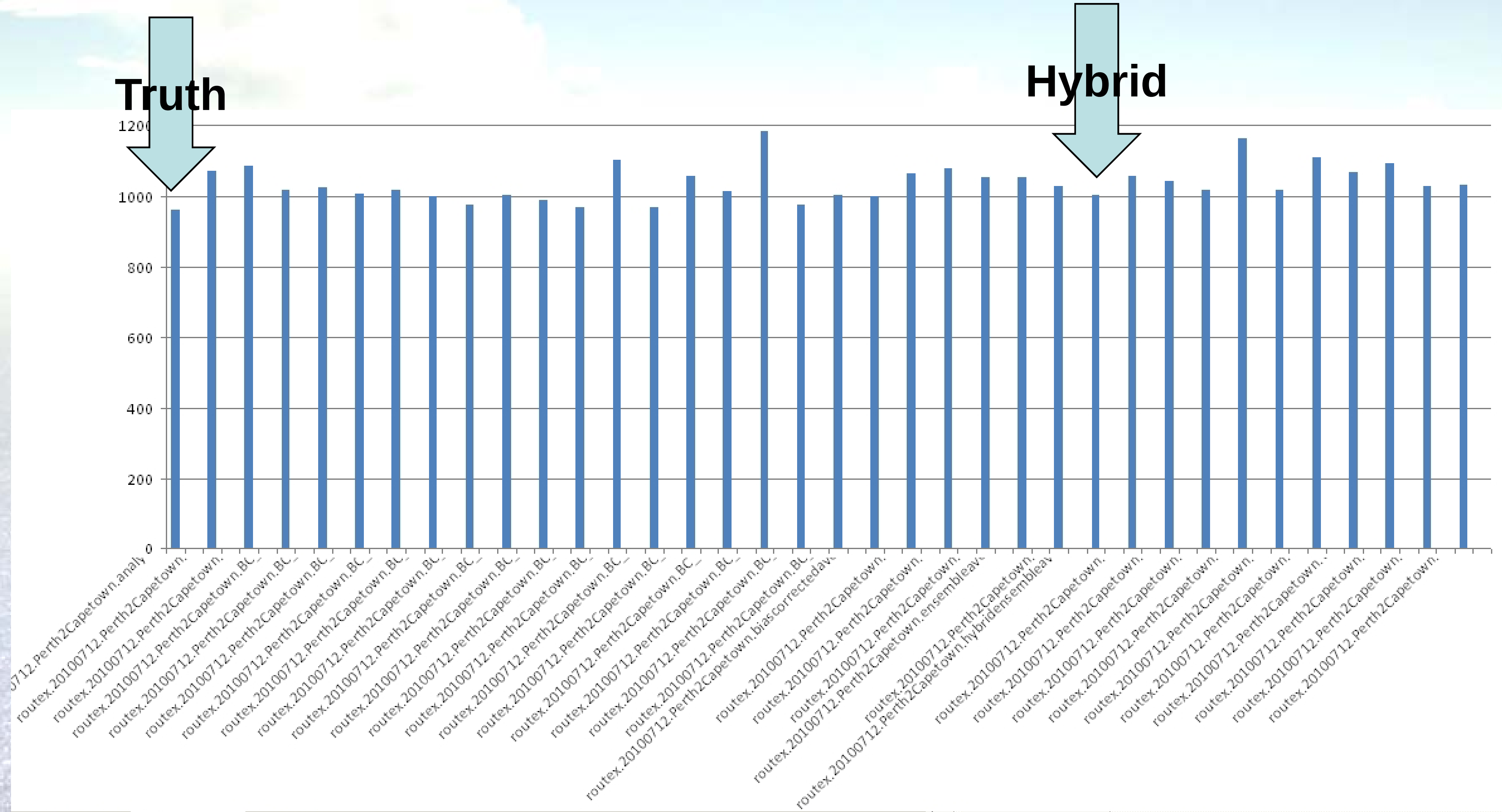
HYBRID Horse Power
1530



Impact of Climatology
Added distance/Horse Power

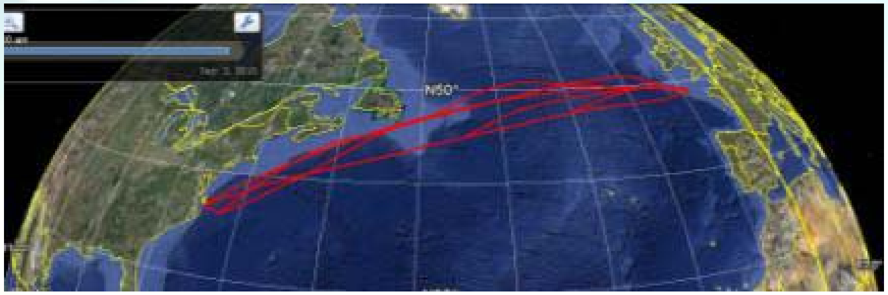
Post Analysis Route Horse Power
1570

Horse Power Expended



- **On average, the Hybrid route provides the HP expenditure closest to the analysis "truth"**
- **To score the routes, need to sail each route through the analysis "truth"**

Smart Ship Routing using EFAS



Norfolk, VA to English Channel
28 Aug 2010

HP Average =	1130.2	Min HP =	1072.6
		Max HP =	1305.8
HP Truth =	1108.9	Delta HP =	233.2
Hybrid HP =	1136.8	% Variation =	20.6%
		Min Dist =	2943.5
		Max Dist =	3038.7
Ave Distance =	2990.1	Delta Dist =	95.2
		% Variation =	3%

Ensemble Sailing GC w/ no Optimizer

HP Average =	1089.8	Min HP =	1023.3
		Max HP =	1276.7
		Delta HP =	253.4
		% Variation =	23.3%
Distance =	2084		

English Channel to Norfolk, VA
31 Aug 2010

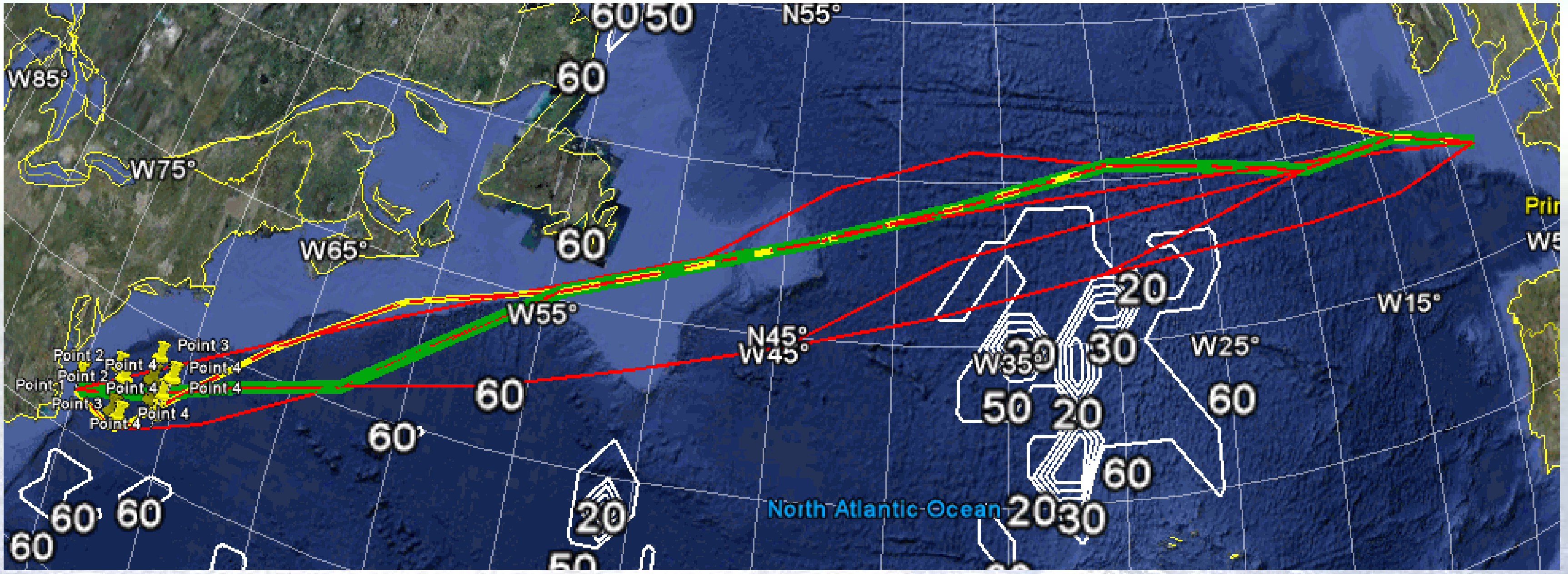
HP Average =	1220.1	Min HP =	1105.1
		Max HP =	1472.5
HP Truth =	1252.5	Delta HP =	367.4
Hybrid HP=	1214.3	% Variation =	30.1%
		Min Dist =	2943.5
		Max Dist =	3002.0
Ave Distance =	2969.6	Delta Dist =	58.5
		% Variation =	2%

Ensemble Sailing GC w/ no Optimizer

HP Average =	1195.2	Min HP =	1100.6
		Max HP =	1372.9
		Delta HP =	272.3
		% Variation =	22.8%
Distance =	2084		

Norfolk, VA to English Channel Routes with Wind Confidence Chart

Confidence: percentage of ensemble grid points within a user-specified forecast error tolerance



	Arrival Time =	201009032123
HYBRID Ensemble	Horse Power =	1136.8
	Distance =	3018.6
	Arrival Time =	201009032123
Analysis FCST Route	Horse Power =	1108.9
	Distance =	2974.9

Value of Smart Ship Routing

1. EFAS – STARS may help reduce US Navy fuel expenditure
   - In our limited tests (60 routes) the horse power expended varies between 8% to 30% across the ensembles
   - Hybrid ensemble average shows improvement of up to 10% over a randomly selected ensemble member
   - At $70/bbl, each 1% improvement in routing saves about $7.5 M/yr in fuel costs

2. Can the improved forecast be shown to avoid costs of damage from heavy weather, reducing yard time/repair & extending service life?
   - ADM Harvey - Keeping ships in shape to make their 25-, or 30- or even 40-year planned operational life spans is fundamental to the Navy's three-decade fleet plan. And that plan is already aggressive: it will push many ships, including cruisers, destroyers and amphibious ships, as much as 10 or 15 years beyond their original design life.
   - $???? B can be avoided in Ship Repair
   - $???? B can be put into Ship Building

Summary

- Decision makers and operators require timely information and guidance for planning, improved safety and operational efficiency
- Ensembles can be represented into a deterministic-like Consensus Forecast that conveys:
  - A consensus value (presently we use an average of the post processed ensemble)
  - Confidence in the consensus within a user-defined tolerance of forecast error
- Regarding Post-Processing:
  - The model analysis is used for ensemble bias corrections and calibrations of the grid
  - In most cases, for our parameters, bias correction gives best results
  - 30 day training period sufficient to condition the ensemble
- The consensus forecast outperforms the deterministic forecast
- This provides a method to interface TDAs to METOC ensembles

Future Work

- Compute the fuel usage for each route through the "truth" and evaluate the fuel penalties
- Develop a technique for deriving confidence in fuel usage calculations
- Extend our ensemble database from 144 to 240 hrs
- Introduce ocean currents and SST ensembles
- Evaluate mesoscale ensembles to improve near land transits
- Develop improved bias correction (testing Kalman filter) and spread adjustment methods
- Evaluate "Best Member" and "Most Likely Value" approaches
- Implement improved ship and power models used for optimization of the type being developed for Tempest (US Navy's next-generation sea-keeping and dynamic stability software)