Smart Voyage Planning (SVP) Model Sensitivity Analysis using Ocean and Atmospheric Models including Ensemble Methods

LCDR Scott Miller

GOALS

- Assess the impact and sensitivity of ocean and atmospheric modeling input parameters for an optimum ship routing model
- Determine required sensitivities of model resolution/accuracy in relation to Smart Voyage Plan (SVP) model route optimization
- Use Ensemble Methods for quantifying the environmental model uncertainties and improve forecast skill
- Determine benefits of using realistic speed reduction curves for various classes of Naval vessels

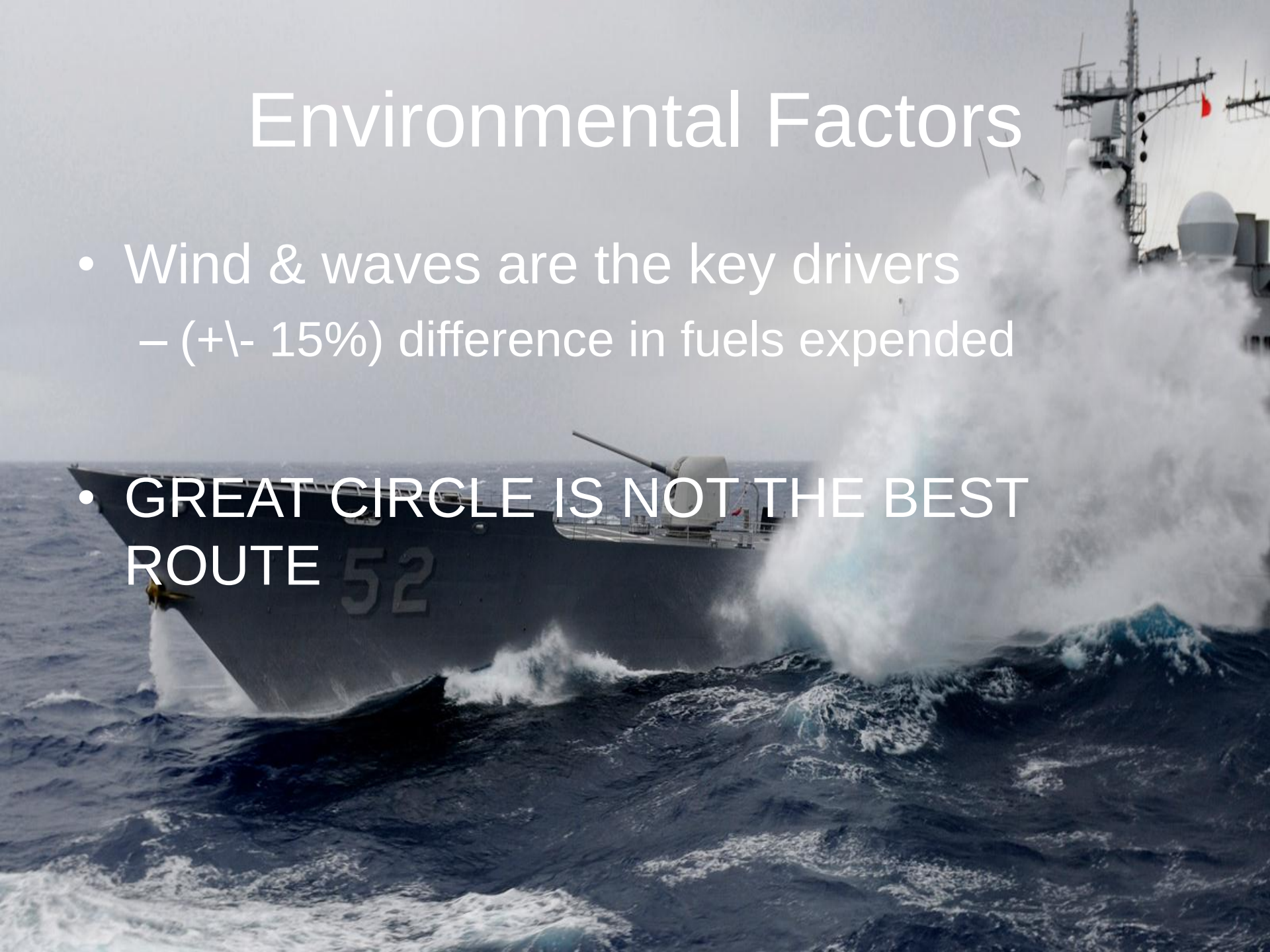
Environmental Factors

- First order: RESISTANCE (not distance)
  - Non-linear
  - Proportional to wind cubed above 35kts (wind causes ~1/3 of resistance below 35kts, varies with relative direction)
- Second order: Wave magnitude and direction
  - Positive or negative
  - Critical when wavelength is =~ size of ship
  - Adds resistance and changes propeller characteristics
  - Drift and direction, especially in quartering seas
- Currents: straightforward
  - +\- ~1/2 knot
  - 1-2 knots in boundary currents (positive or negative)
  - Varies with wind

Environmental Factors

- Wind & waves are the key drivers
  - (+\- 15%) difference in fuels expended

- GREAT CIRCLE IS NOT THE BEST ROUTE



Key Questions

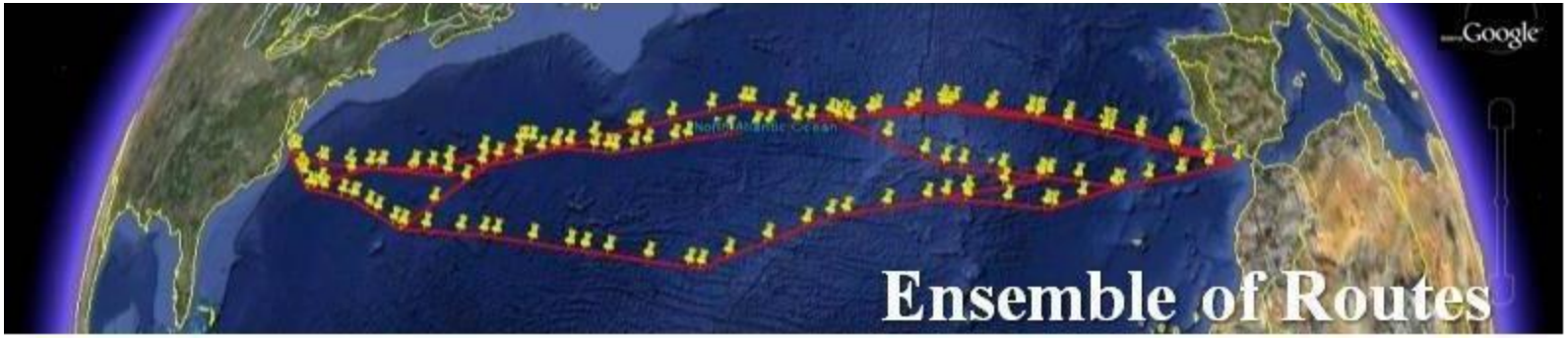
- What are the conditions or requirements that impact the quality of input values?
- Which input values carry the highest sensitivity for the SVP system & what is the rank ordering of the sensitivity?
- What are the points of diminishing return? What resolution/accuracy is good enough?
- How should uncertainty and sensitivity be communicated? What effects does it have on routing improvements routing or degradation?

Key Questions

- With enhanced model output, what is the improvement in the least cost route as compared to the best possible route using actual hindcast environmental data in SVP models?
- What effect do platform characteristics have on the outcome of the least cost route? (e.g. accurate hull modeling, platform loading, power curves)
- How does utilizing environmental model ensemble methods affect the improvement in SVP model output optimization?

Time and Space

- Perform sensitivity analysis for at least one year to ensure seasonality effects are observed
- Ensure ship tracks are run over various regions of the globe to observe regional effects



Ensembles Methods

- Account for two sources of uncertainty in weather forecast models:

  (1) Errors introduced by chaos or sensitive dependence on the initial conditions

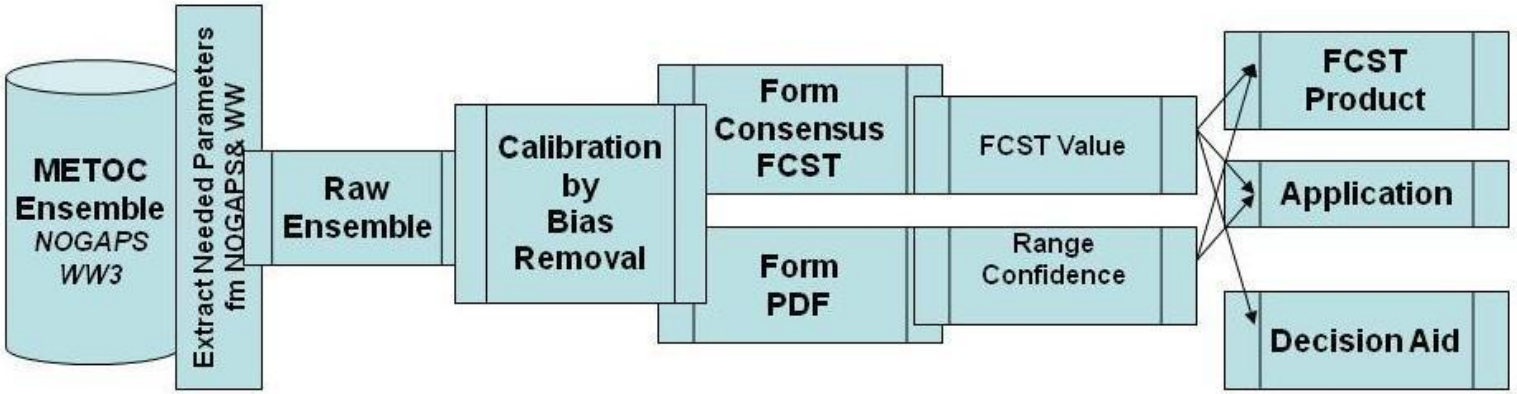
  (2) Errors introduced because of imperfections in the model, such as the finite grid spacing

- The verified weather pattern should fall within past ensemble spreads and amount of spread should be related to probability of certain weather events occurring
  - Key in increasing forecast skill for better route predictions

Ensembles Methods

Utilize the following ensembles methods for SVP model input compared to output optimizations:

- Standard Ensemble Mean
- Ensemble Kalman Filter (EnKF) – improve bias correction accuracy
- Least squares analysis to determine the Most Likely Value for the best fit individual ensemble member



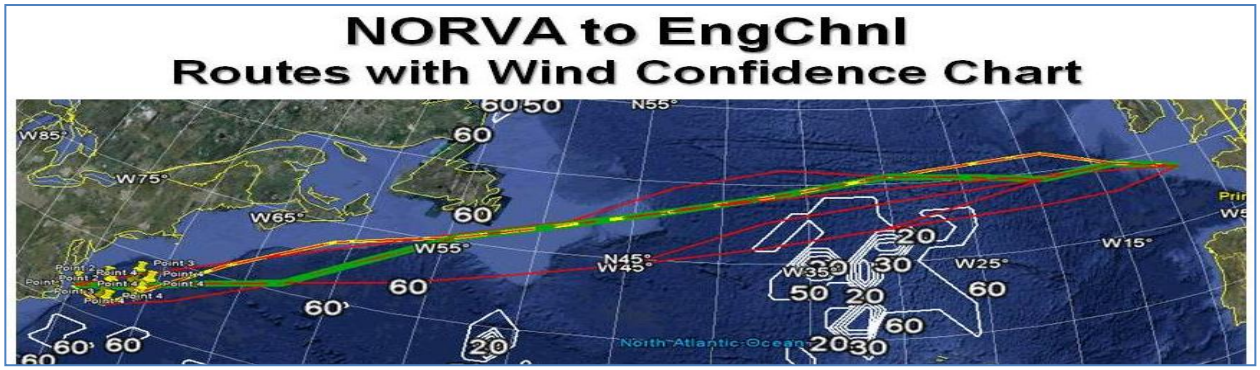
Ensembles Methods

- Improve accuracy of surface wind and wave spectra forecast ensembles and the members selected for guidance

- Return on Smart Ship Routing Investment
  - good route optimization with current METOC products saves 4%
  - more accurate (ensemble) forecast could add another 4%-8% fuel savings
  - eliminates involuntary fuel expenditure from bad forecasts

- Very Important for Safety and Safe Operating Envelope

Ensembles Methods



- Ensembles from NOGAPS and WW3
  - –10-day forecast, 16 ensemble members at 1 degree resolution
  - –Interfaced the forecasts to the TDA and form an ensemble of routes
  - –Choose the most efficient route and compare performance w/o ensemble:
    - +\- 2% spread in the distance traveled
    - +\- 15% difference in fuels expended (wind & waves were the key resistances)

Consensus Forecasts for Smart Routing

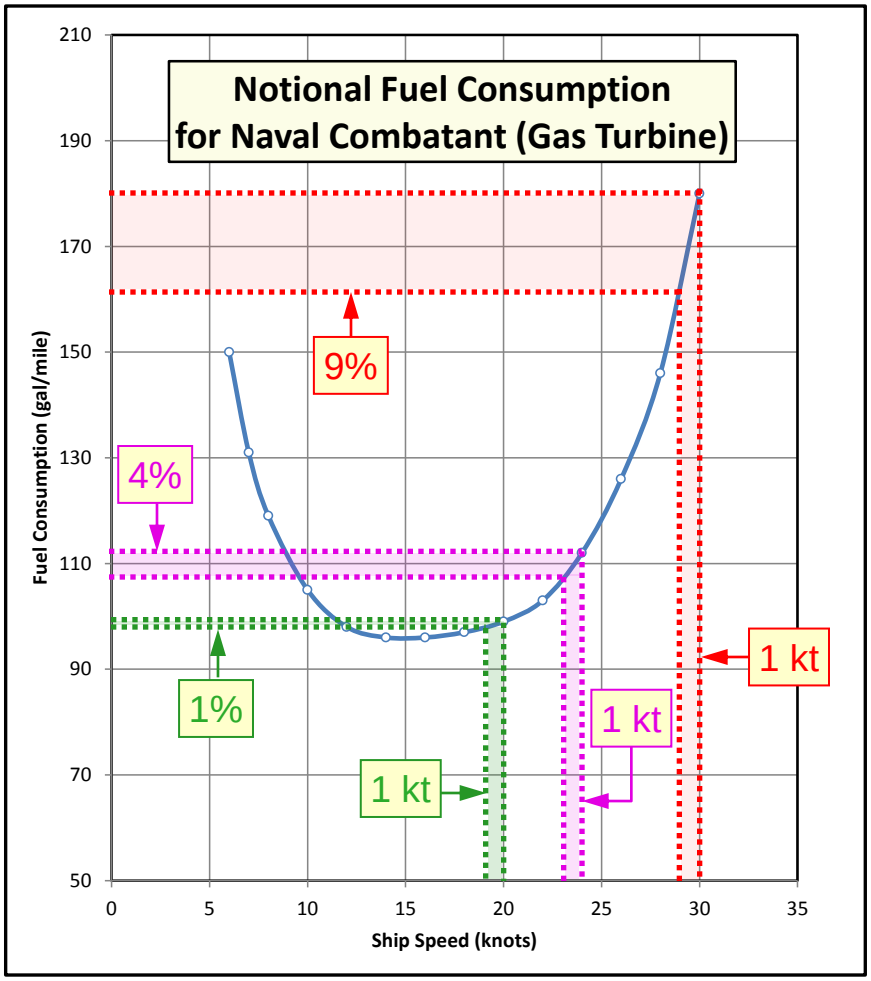
Post Processed Ensemble Forecast Improvement			
Needed Parameters	24 Hr FCST	72 Hr FCST	144 Hr FCST
SWL_WAVE_DIR	BIAS_CORR	RAW	RAW
SWL_WAVE_HT	BIAS_CORR	BIAS_CORR	BIAS_CORR
SWL_WAVE_PER	BIAS_CORR	BIAS_CORR	BIAS_CORR
WIND_DIR	RAW	RAW	RAW
WIND_SPD	BIAS_CORR	BIAS_CORR	RAW
WIND_WAVE_DIR	BIAS_CORR	BIAS_CORR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

Fuel Consumption – Sensitivity To Ship Speed

- Ship fuel consumption rate increases rapidly with ship speed
- Fuel consumption increases by ~1 to 4% per knot at moderate speeds
- Fuel consumption increases by ~9% per knot at high speeds

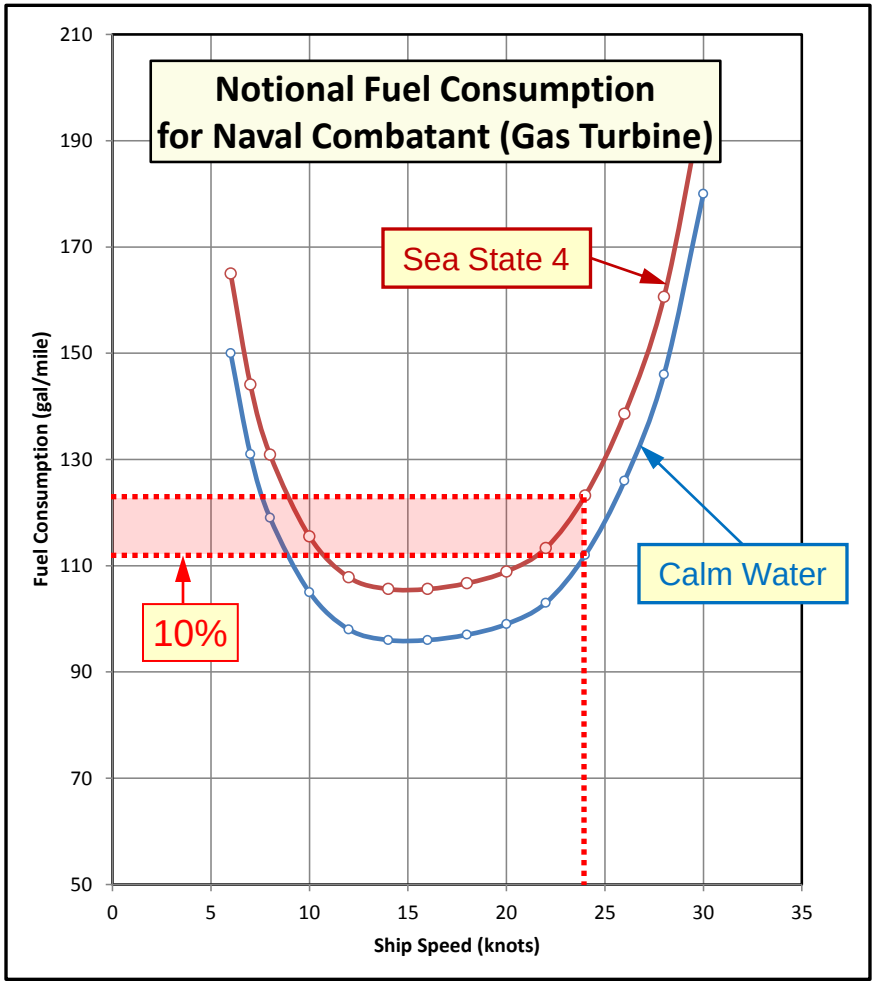
Optimizing the ship speed profile during transit can yield significant fuel savings



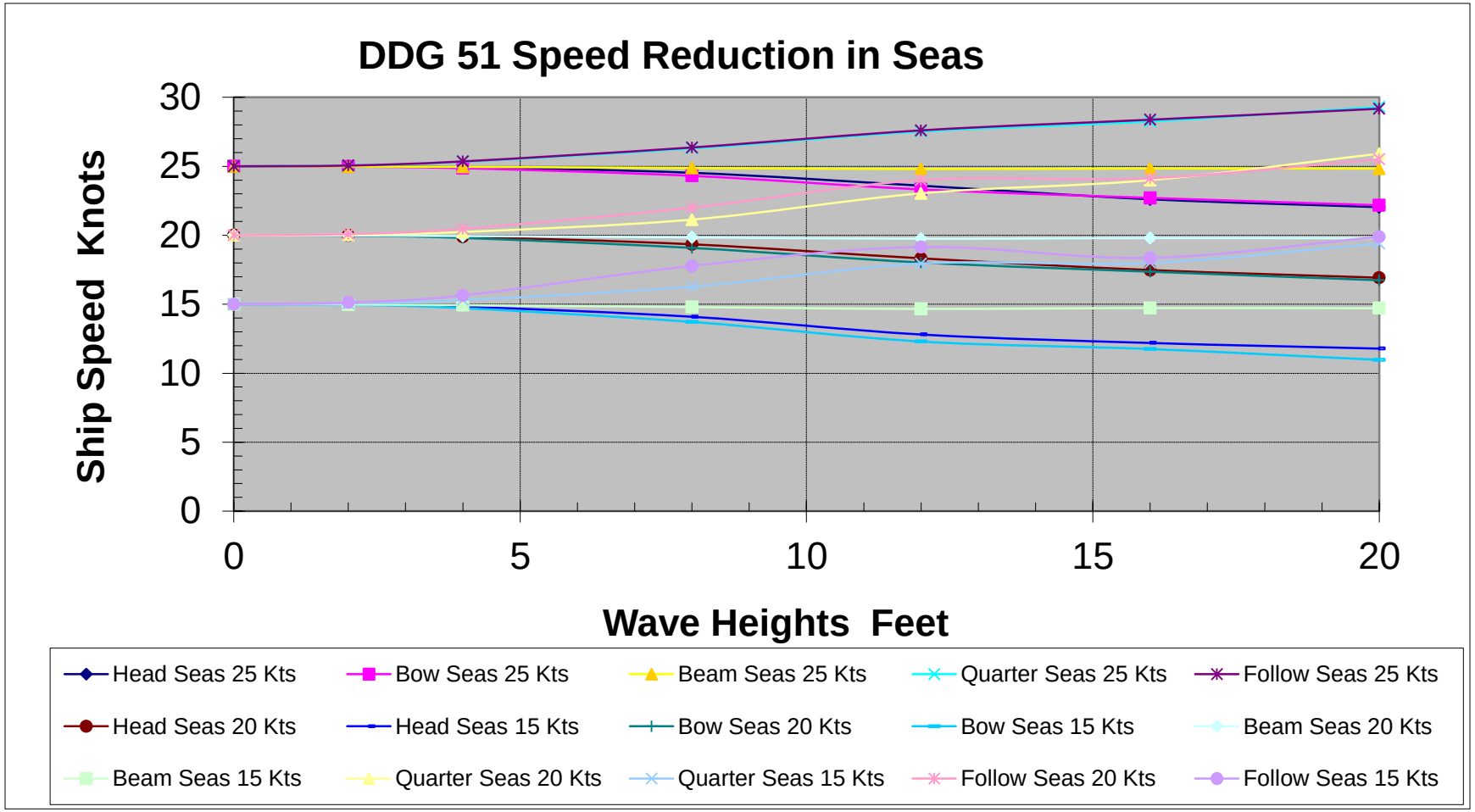
Fuel Consumption – Sensitivity To Environment

- Ship fuel consumption rate increases significantly with moderate waves, wind, and current
- At constant speed, fuel consumption in Sea State 4 with a 1 knot current increases by ~10% over calm water value

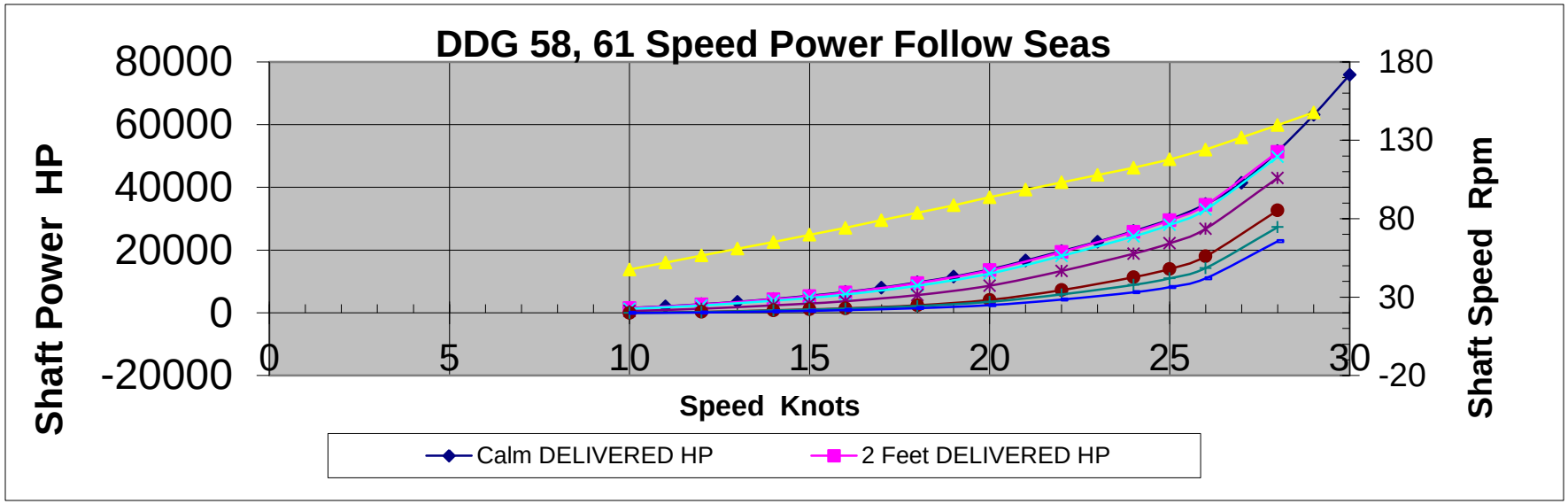
Optimizing the ship route together with the speed profile to avoid adverse environmental conditions during transit can yield even greater fuel savings

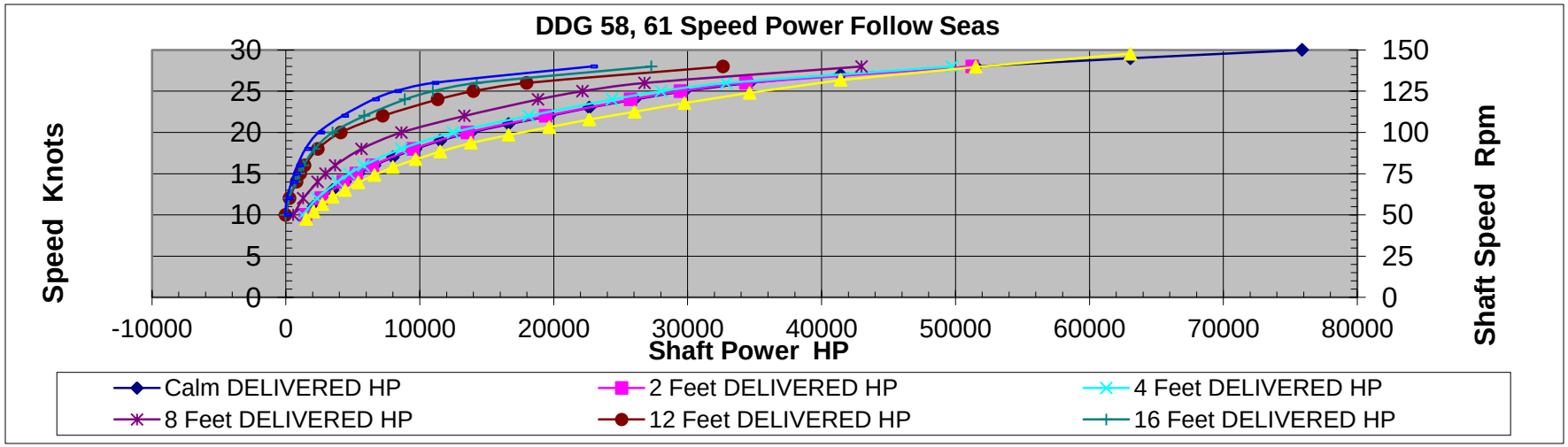


Fuel Consumption – Sensitivity To Environment



Fuel Consumption – Sensitivity To Environment





Benefits of Study

- Evaluate next generation modeling efforts by linking improved outputs to energy conservation/cost avoidance
- Identify the most important SVP model inputs focusing resources to improve critical environmental model outputs
- Fuel savings on the order of 5-10% (annual cost savings in the 10’s of millions of dollars) & higher during Winter seasons
- Reduced CO2 emissions (contributing to the green fleet initiative)
- Enhanced model outputs to include greater accuracy and consistency
- Safer operation with improved severe weather avoidance and minimized loss of mission time
- Validates importance of next-gen models and ensemble methods

Questions?