OPTIMIZATION OF SHIP ROUTES: METEOROLOGICAL NAVIGATION "BY NUMERICAL PROCESS"

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NAVIGATION HAS ALWAYS BEEN METEOROLOGICAL


Image from the web: G. Hunt


Steamship Rubi in a storm, Dundee Art Galleries and Museum Collection (Dundee City Council)

METEOROLOGICAL NAVIGATION BY NUMERICAL PROCESS

- DETAILED METEO-MARINE DATA (FORECASTS AND/OR OBSERVATIONS)
- RELIABLE SHIP PERFORMANCES EVALUATIONS
- POWERFULL COMPUTERS

NOT AN AUTOPILOT BUT A VALUABLE HELP FOR THE SHIP MASTER'S DECISION PROCESS

INDEX:

- INTRODUCTION TO WEATHER ROUTING
- COMPUTATION OF SHIP PERFORMANCES ALONG A ROUTE
- A CASE STUDY DEVELOPED IN COSMEMOS
- OPTIMIZATION OF SHIP ROUTES AS AN OPTIMAL CONTROL PROBLEM

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WEATHER ROUTING, SHORT TIMELINE:

- **STARTING FROM 1950:** MINIMAL TIME OCEAN ROUTING
  - LOW SPACE-TIME RESOLUTION OF METEO DATA
  - VERY SIMPLE SHIP MODELS
- **IMPROVEMENT** OF METEO-MARINE FORECAST MODELS AND GROWTH OF COMPUTERS POWER; DEVELOPEMENTS IN SHIP HYDRODYNAMICS
- **TODAY:** MANY APPROACHES HAVE BEEN DEVELOPED AND SEVERAL COMMERCIAL SERVICES EXIST, MANLY FOR OCEANIC PASSAGES
- GROWING INTEREST FOR **MEDITERRANENAN SCALE** WEATHER ROUTING: IN RECENT YEARS SEVERAL INTERNATIONAL PROJECTS STUDIED IT
- NOT ALL THE **POTENTIALITIES** HAVE BEEN EXPLOITED:
  - MANY METEO-MARINE DATA FROM FORECAST MODELS
  - IMPROVED SHIP MODELS
  - COMPUTERS POWER

COSMEMOS:

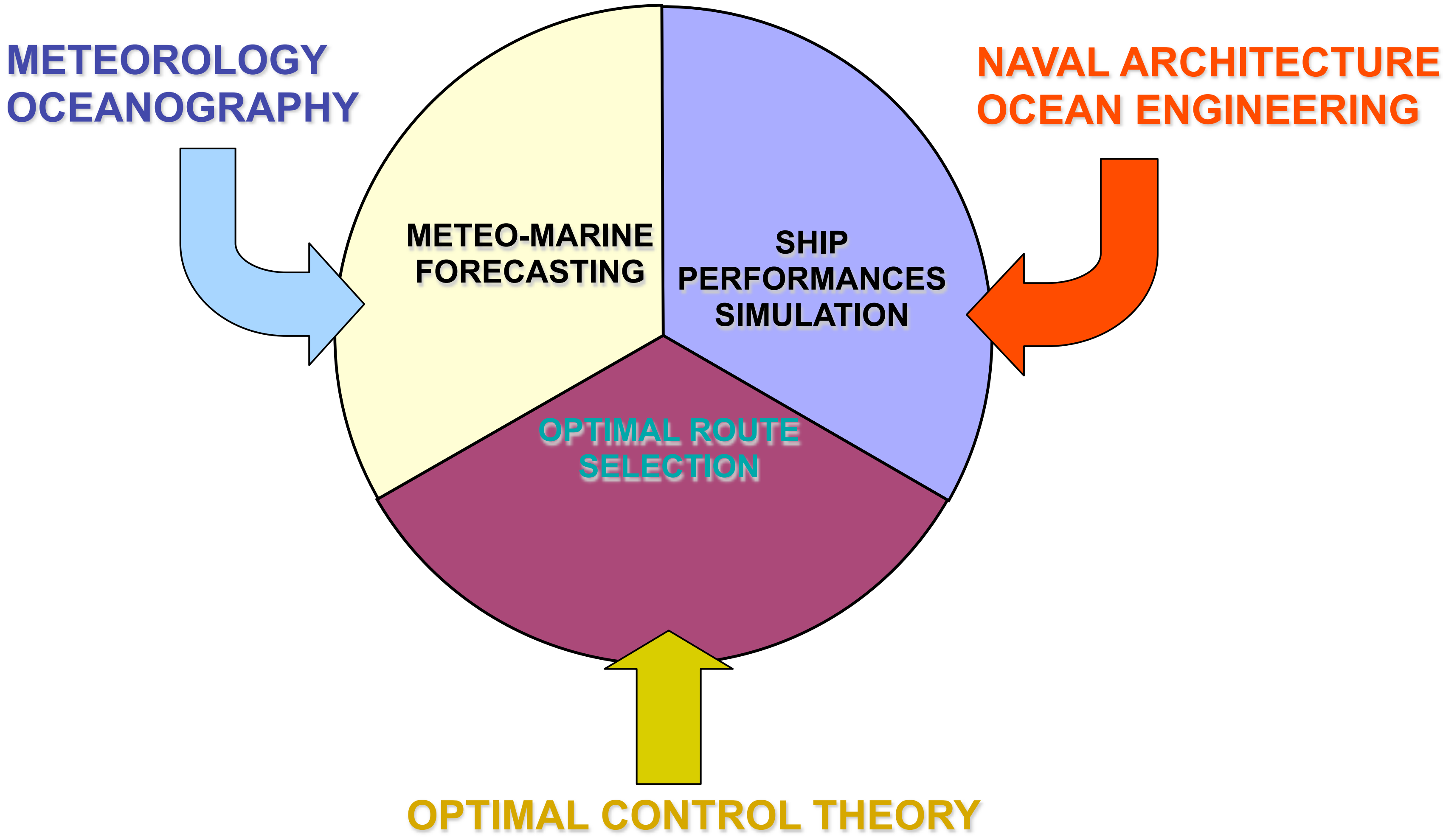
METEO-MARINE FORECASTS:

- IMPROVE DATA COLLECTION AT SEA
- DEVELOPE INNOVATIVE DATA ANALYSIS AND DATA FUSION TECHNIQUES
- IMPROVE HIGH RESOLUITON LOCAL AREA METEO-MARINE FORECAST MODELS BY HIGH RESOLUTION DATA ASSIMILATION

WEATHER ROUTING AT THE MEDITERRANEAN SCALE:

- ENCLOSED SEA: RELATIVELY SHORT DISTANCES, MANY CONSTRAINTS, VERY COMPLEX METEOROLOGICAL VARIABILITY
  - ROUTING BASED ON HIGH RESOLUTION METEO-MARINE FORECASTS
  - DETAILED MODELLIZATION OF SHIP-ENVIRONMENT INTERACTIONS

METEOROLOGICAL NAVIGATION TODAY:
A STRONGLY INTERDISHIPLINARY FIELD



INTEGRATION OF THREE STRONGLY RELATED FIELDS:

- SHIP DESIGN
- WEATHER ROUTING
- OPERATIONAL GUIDANCE SYSTEMS

FOR ALL THREE ITEMS THE GOAL IS TO SOLVE A COMPLEX MULTI-OBJECTIVE OPTIMIZATION PROBLEM

SHIP DESIGN
VS
WEATHER ROUTING

- **SHIP DESIGN**:

  OPTIMIZE THE CHARACTERISTICS OF A SHIP

  IN ORDER TO OPERATE AT BEST IN

  GIVEN AVERAGE METEO-MARINE CONDITIONS

- **WEATHER ROUTING**:

  OPTIMIZE (GLOBALLY) THE ROUTE

  GIVEN THE CHARACTERISTICS OF THE SHIP

  WITH METEO-MARINE CONDITIONS
  FROM FORECAST MODELS

SHIP DESIGN
VS
OPERATIONAL GUIDANCE SYSTEMS

- **SHIP DESIGN**:

  OPTIMIZE THE CHARACTERISTICS OF A SHIP

  IN ORDER TO OPERATE AT BEST IN

  GIVEN AVERAGE METEO-MARINE CONDITIONS

- **OPERATIONAL GUIDANCE SYSTEMS**:

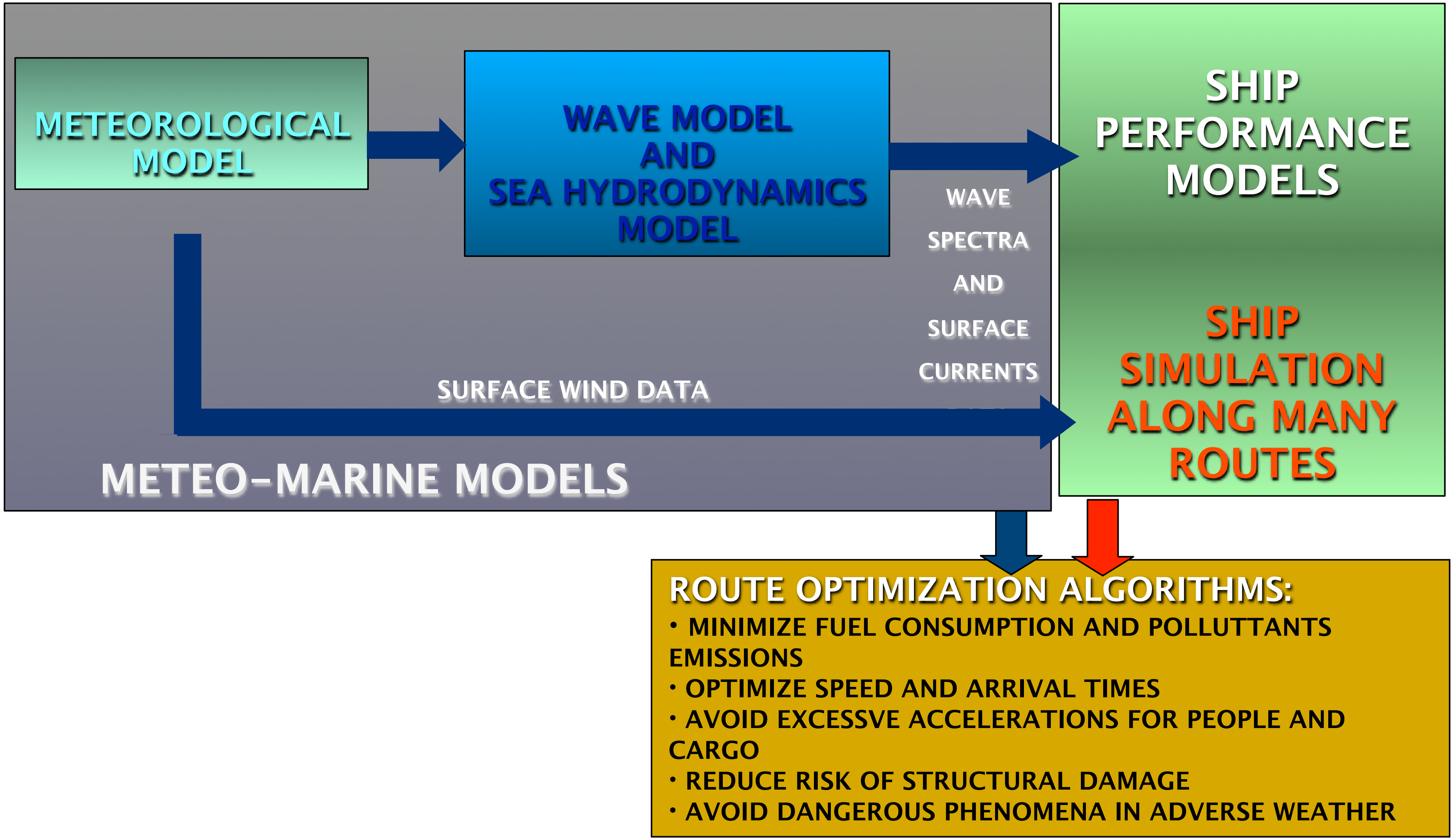
  OPTIMIZE (LOCALLY) THE ROUTE

  GIVEN THE CHARACTERISTICS OF THE SHIP

  WITH METEO-MARINE CONDITIONS
  FROM REAL-TIME ONBOARD SENSORS

Innovation in meteorology for maritime navigation
COSMEMOS Project Workshop – Leghorn 23 October 2013

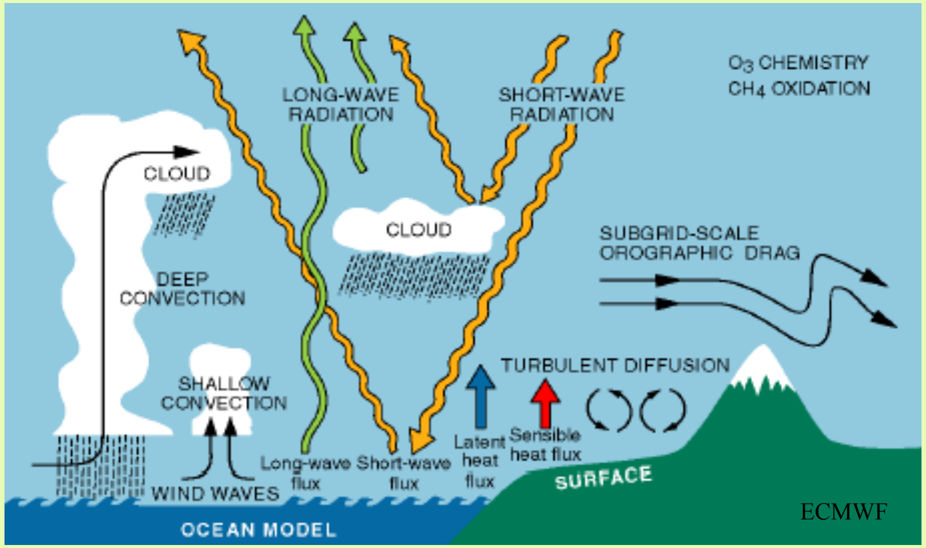
OPTIMIZATION OF SHIP ROUTES: THE GENERAL SCHEME



OPERATIONAL METEO-MARINE FORECASTING:

WIND PREDICTION

NUMERICAL WEATHER PREDICTION (NWP) IS A THERMO-FLUIDODYNAMIC INITIAL VALUES PROBLEM I.E.



NUMERICAL SOLUTION OF

ATMOSPHERIC RANSE

COUPLED WITH SUBGRID SCALE

PARAMETRIZATIONS

AND WITH GIVEN

INITIAL CONDITIONS

OPERATIONAL METEO-MARINE FORECASTING:

CURRENTS PREDICTION

NUMERICAL PREDICTION OF OCEAN HYDRODYNAMICS IS A THERMO-FLUIDODYNAMIC INITIAL VALUES PROBLEM

I.E.

NUMERICAL SOLUTION OF

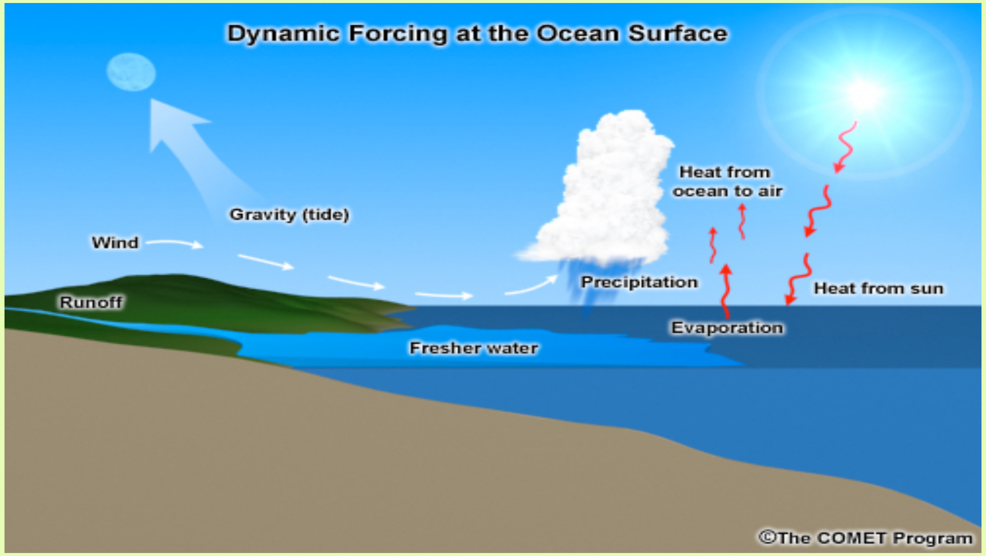
OCEAN RANSE

COUPLED WITH SUBGRID SCALE

PARAMETRIZATIONS

AND WITH GIVEN

INITIAL CONDITIONS

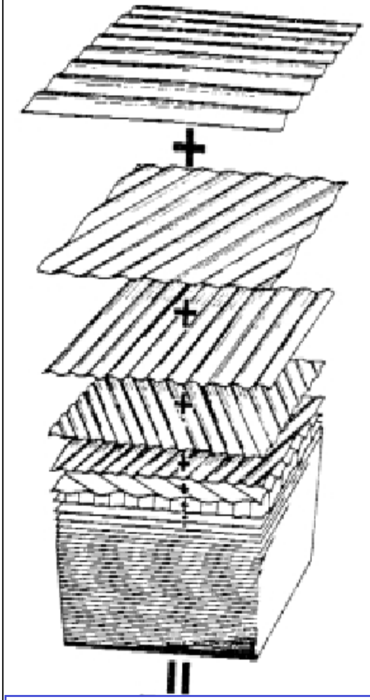


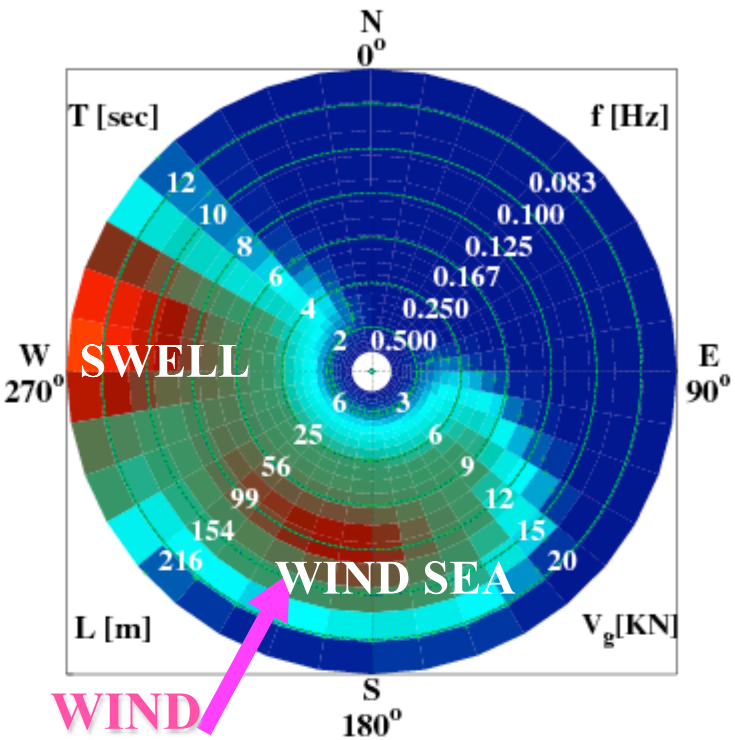
OPERATIONAL METEO-MARINE FORECASTING: WAVE PREDICTION

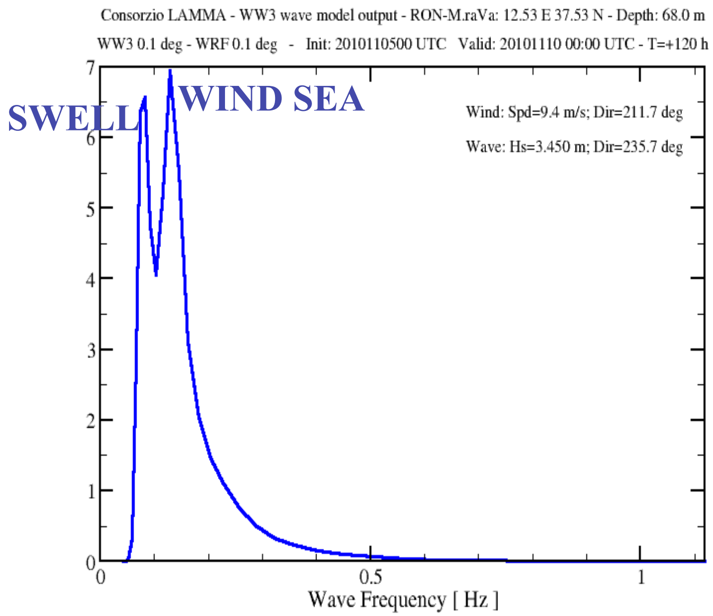
$$\frac{\partial E}{\partial t} + \nabla \bullet (c_g E) = S = S_{in} + S_{nl} + S_{ds}$$

Consorzio LAMMA - WW3 wave model output: directional spectrum
WW3 0.1 deg - WRF 0.1 deg

Position: RON-M.raVa 12.53 E 37.53 N - Depth: 68.0 m
Init.: 2010110500 UTC Valid.: 20101110 00:00 UTC - T=+120h







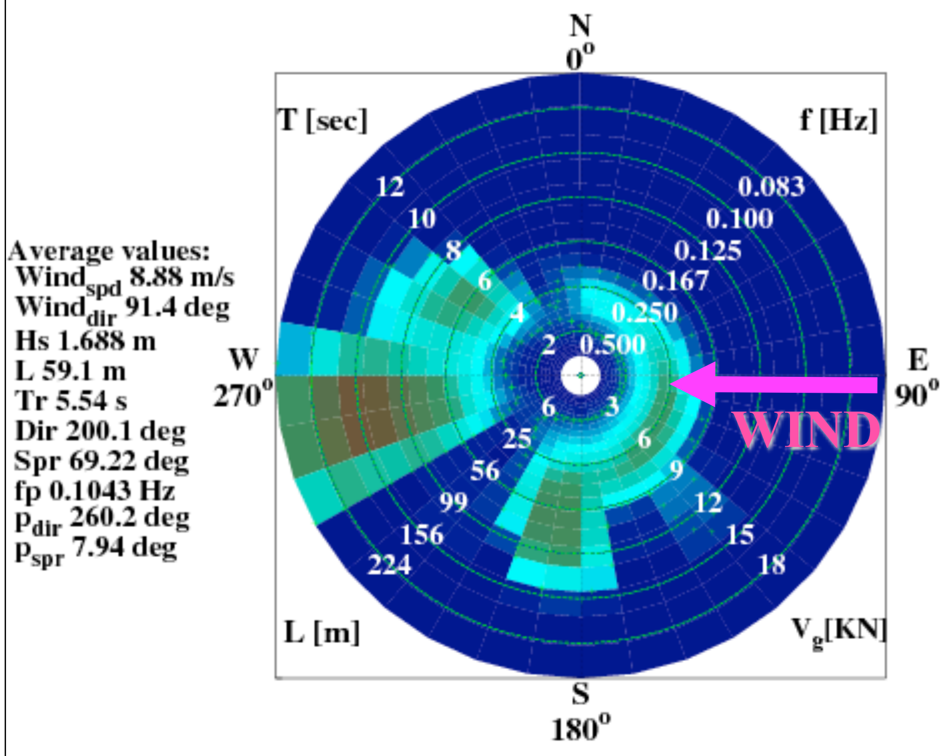
E = E(ω,μ) **WAVE SPECTRUM**

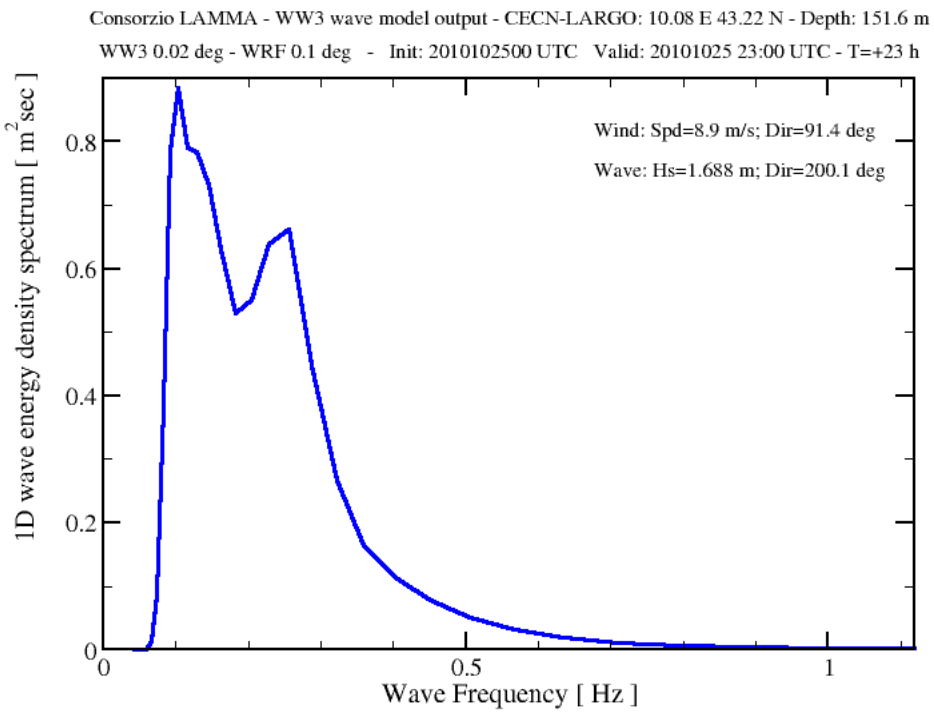
OPERATIONAL METEO-MARINE FORECASTING:

MULTIMODAL WAVE SPECTRA ARE FREQUENT IN REALISTIC SEAWAYS

Consorzio LAMMA - WW3 wave model output: directional spectrum
WW3 0.02 deg - WRF 0.1 deg

Position: CECN-LARGO 10.08 E 43.22 N - Depth: 151.6 m
Init.: 2010102500 UTC Valid.: 20101025 23:00 UTC - T=+23h





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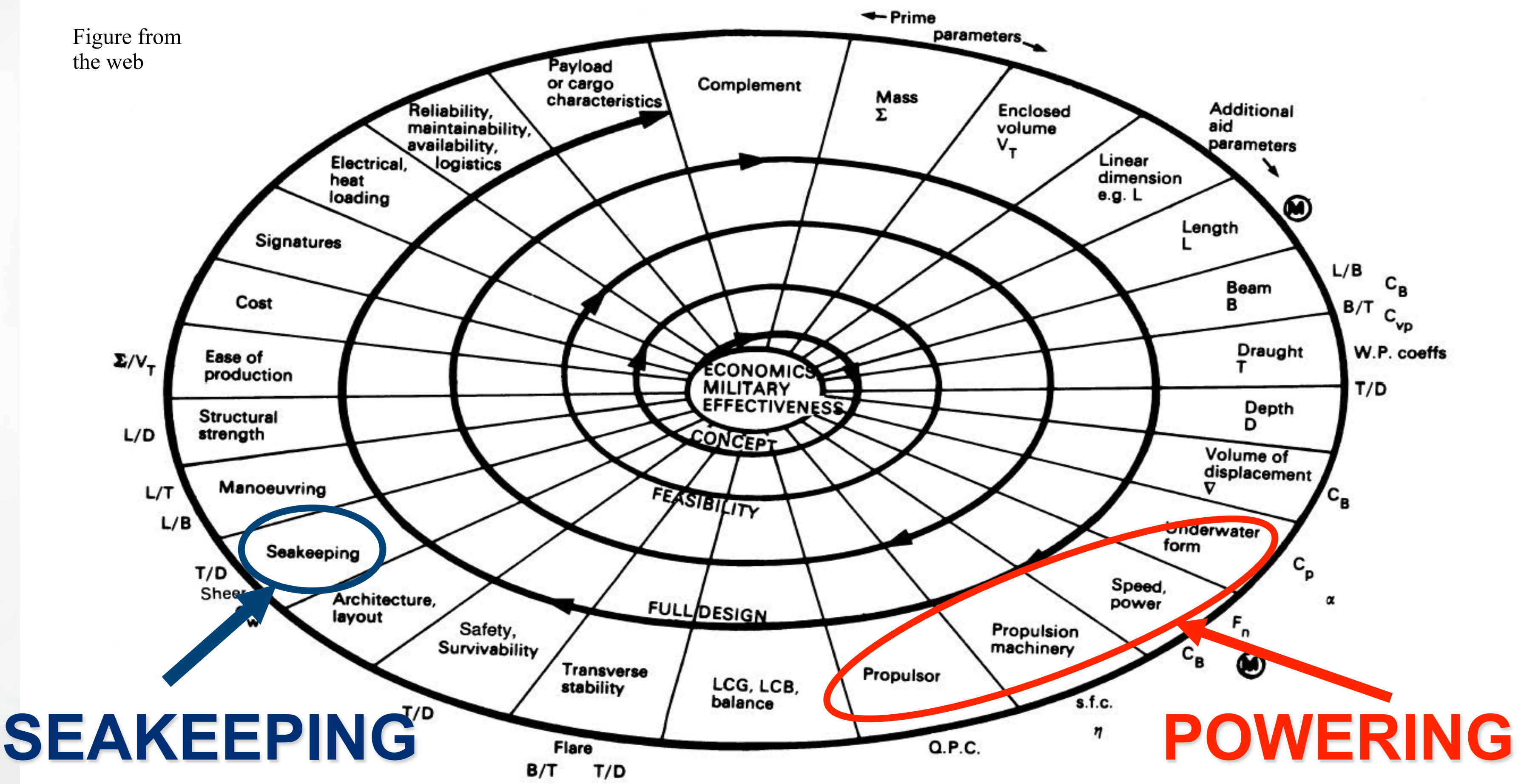
SHIP PERFORMANCE MODELS:

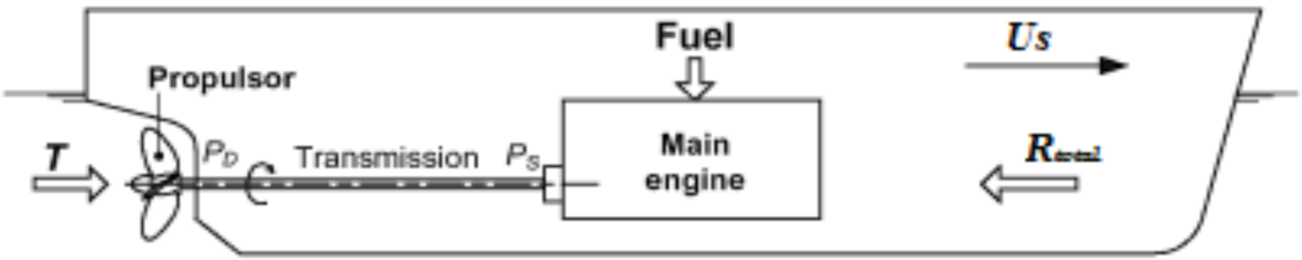
FROM SHIP DESIGN PRACTICE

Figure from the web



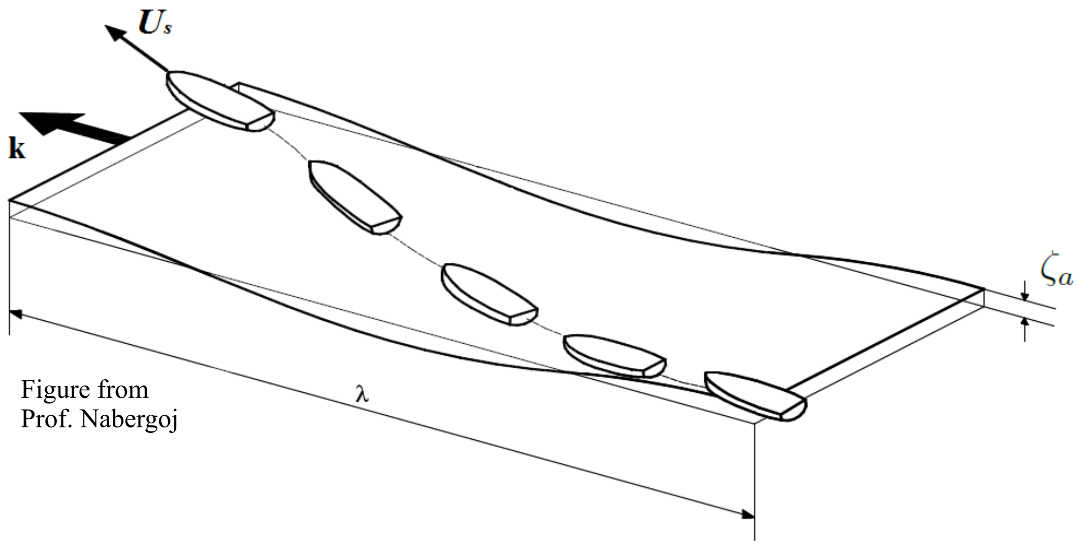
SHIP PERFORMANCE MODELS

POWERING AND SEAKEEPING



POWERING

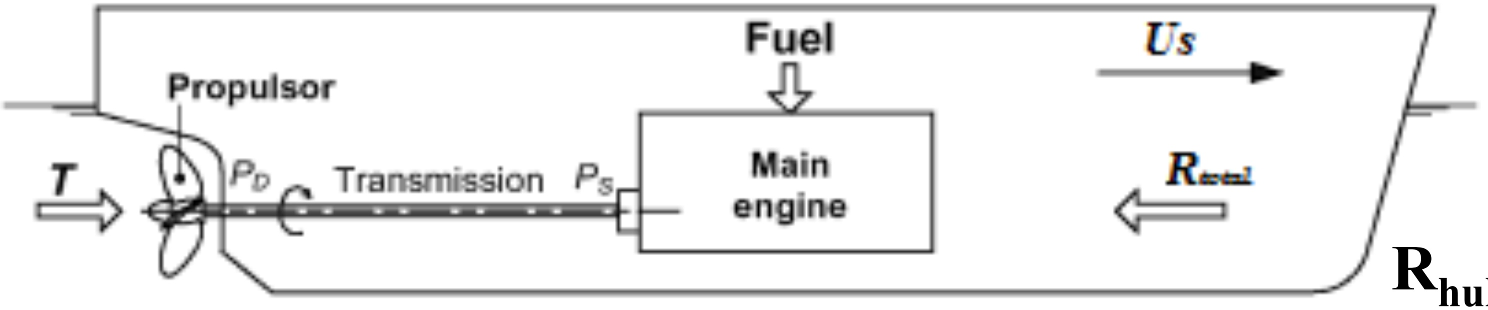
SEAKEEPING



SHIP PERFORMANCE MODELS

POWERING

WIND: R_{wi}



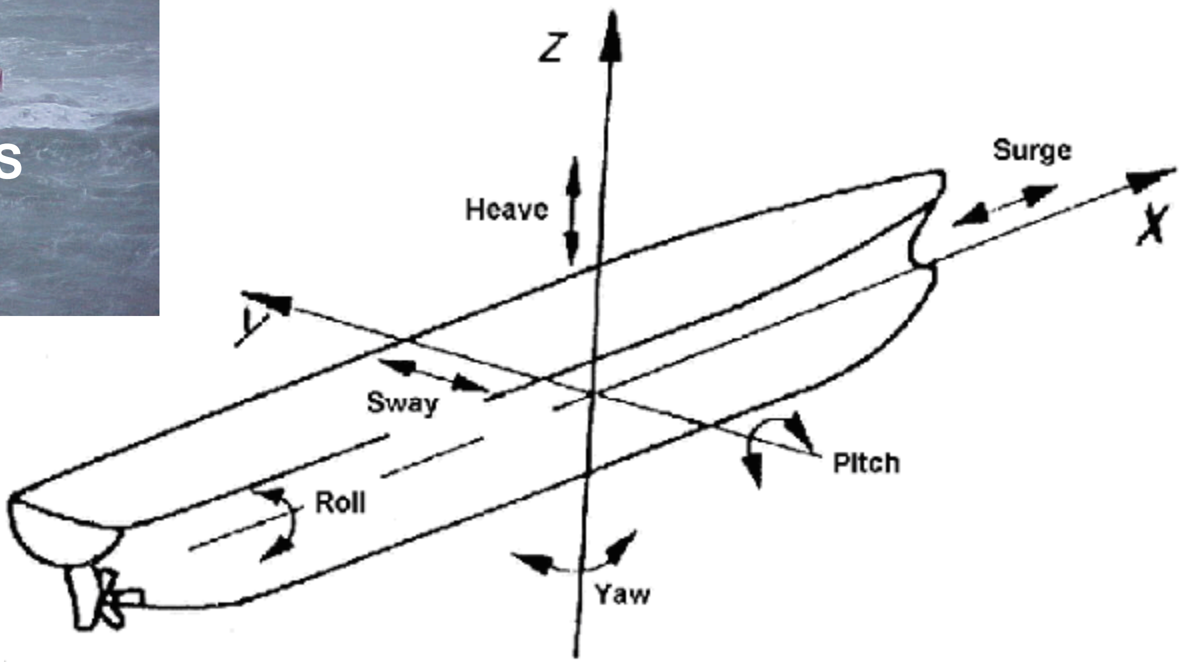
R_{hull}

SEAKEEPING → WAVES: R_{AW}

$$R_{total} = R_{hull}(U_s) + R_{AW}(U_s, \mu_s, [S_\zeta]) + R_{wi}(U_{rwi}, \mu_{rwi})$$

SHIP PERFORMANCE MODELS

SEAKEEPING



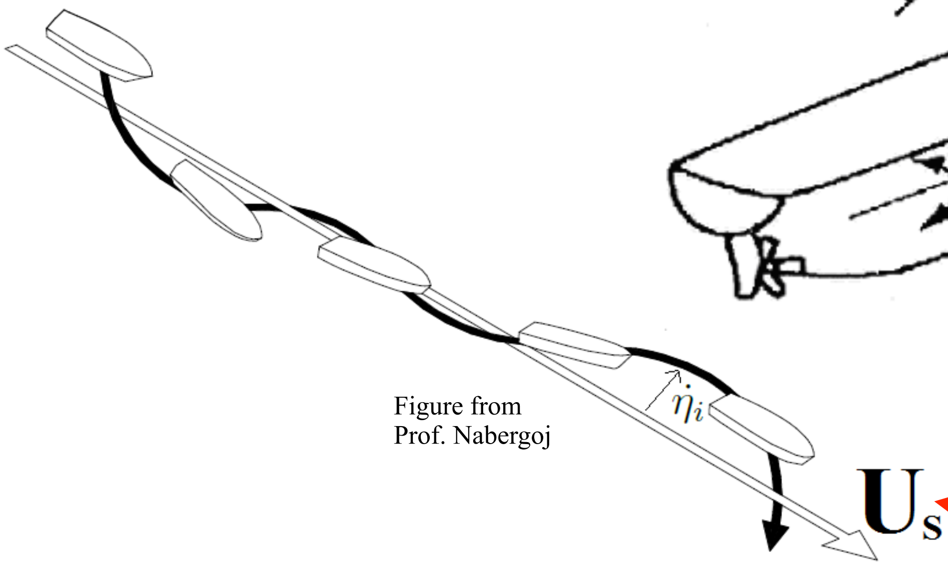


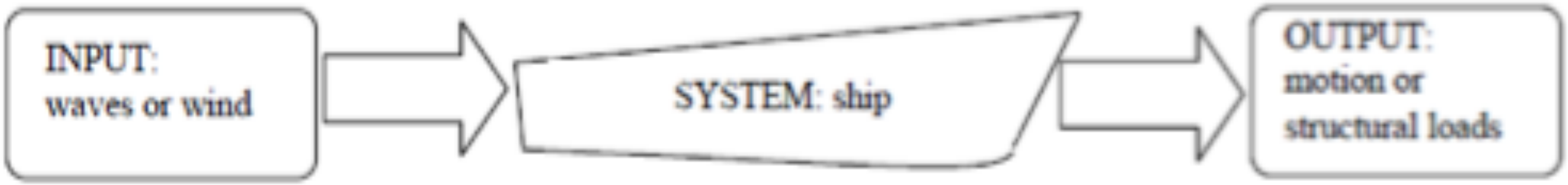
Figure from
Prof. Nabergoj

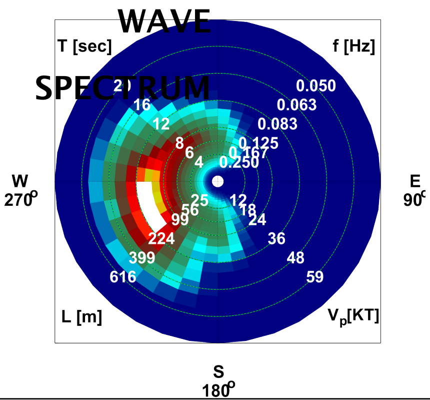
POWERING

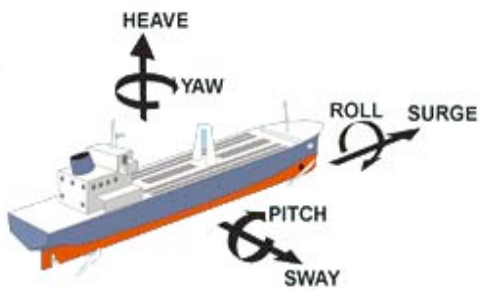
SHIP PERFORMANCE MODELS

SEAKEEPING

IN MANY CASES A LINEAR APPROXIMATION IS ADOPTED







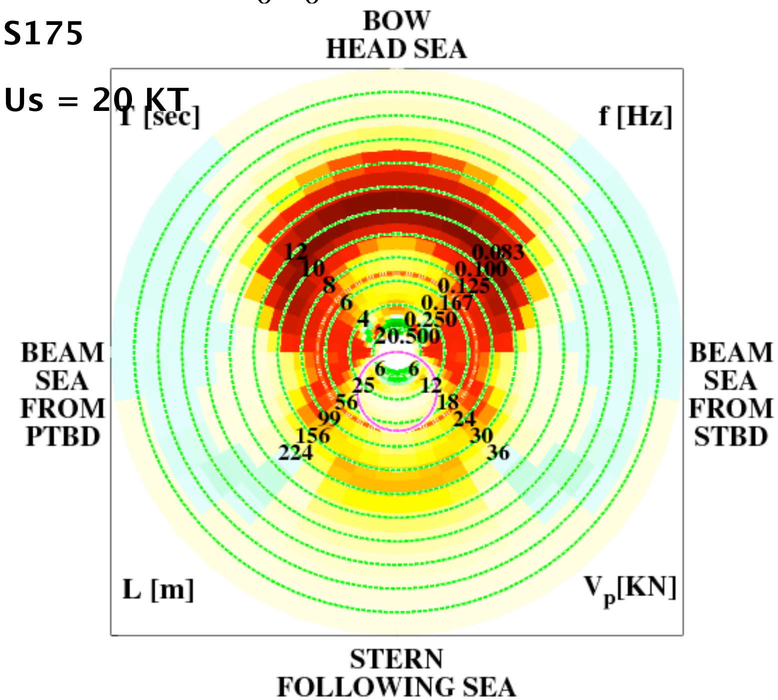
SEAKEEPING AND POWERING: ADDED RESISTANCE IN WAVES

$$R_{total} = R_{hull}(U_s) + R_{AW}(U_s, \mu_s, [S_\zeta]) + R_{wi}(U_{rwi}, \mu_{rwi}) + \Delta R$$

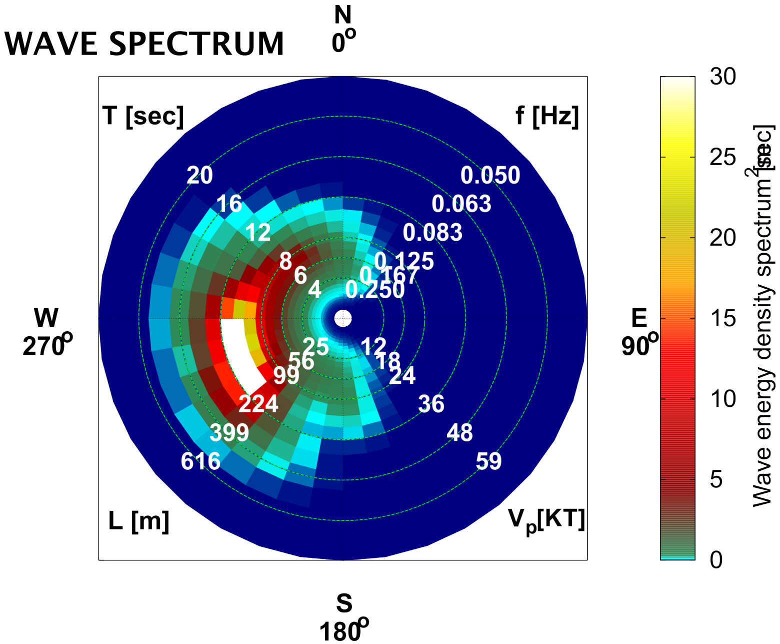
$$R_{aw} = \int_0^{\infty}\int_0^{2\pi} RAO_{aw}(\omega_e(\omega,\theta_r),\theta_r,U_s)\, S_\varsigma(\omega,\theta_r)\, d\theta_r\, d\omega$$

S175

Us = 20 KT



WAVE SPECTRUM



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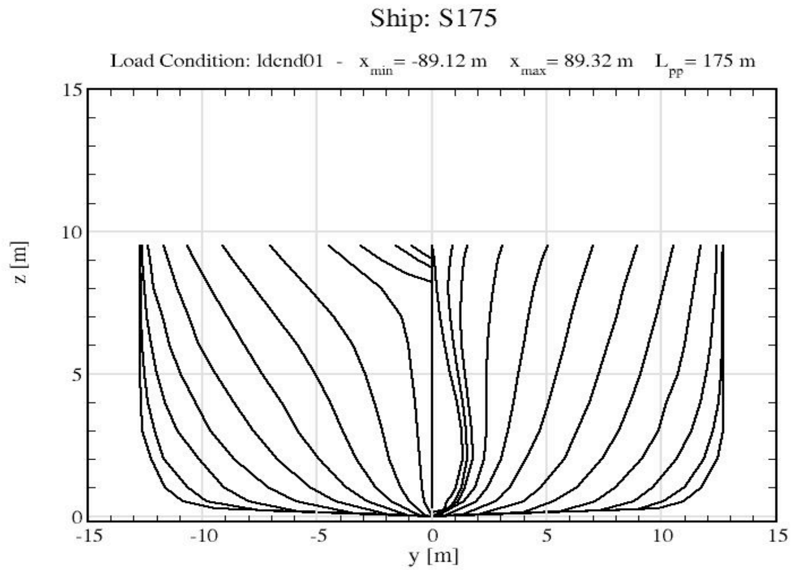
SEAKEEPING AND POWERING ALONG A ROUTE:

A STANDARD EXAMPLE THE S175 CONTAINERSHIP

Name Symbol [units]	Value
Ship length (betw. perp.) L_{pp} [m]	175
Beam B [m]	25
Draft T [m]	9.5
Mass Δ [t]	24609
Roll gyradius k_{xx} [m]	10
Pitch gyradius k_{yy} [m]	42
Yaw gyradius k_{zz} [m]	42



SEAKEEPING AND POWERING ALONG A ROUTE:

ENGINE-PROPELLER MATCHING FOR S175

MAN B&W S50MC-C8-TII

Project Guide

Camshaft Controlled
Two-stroke Engines

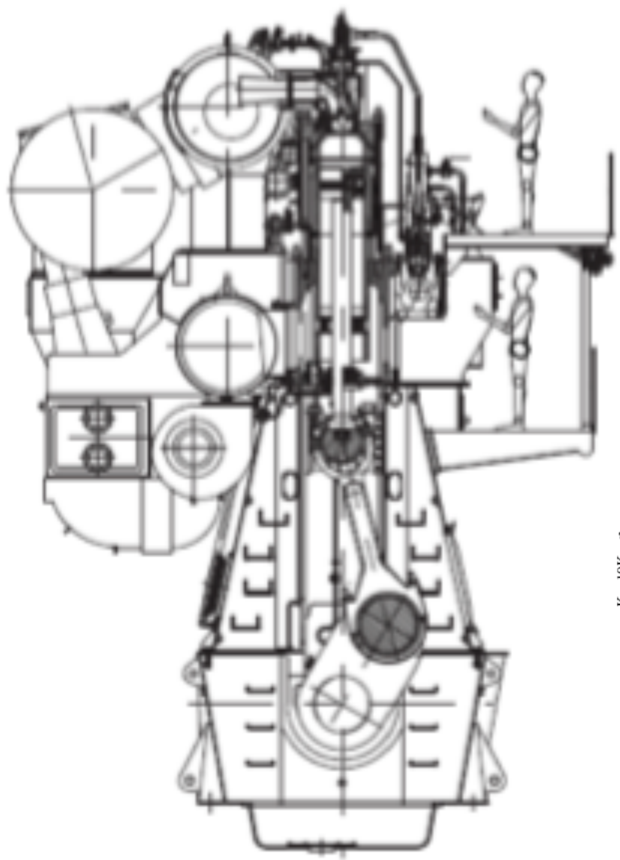
6 S50MC-C8-TII

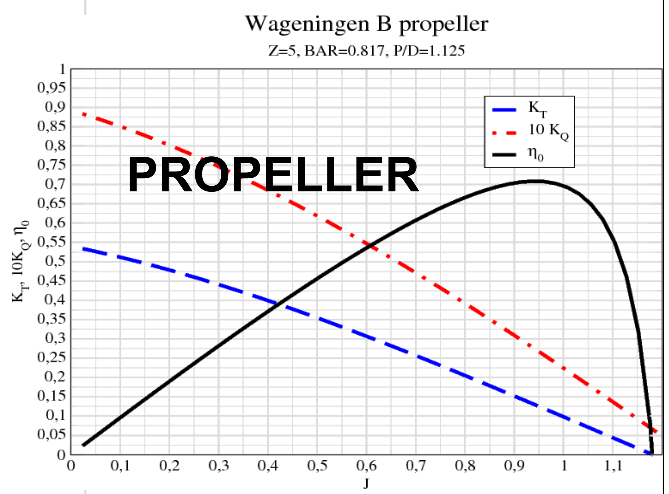
$P_{B\ MCR\ L1}$: 9960 kW

$n_{MCR\ L1}$: 127 r/min

SFOC: 175 g/kWh

Engine Cross Section of S50MC-C8

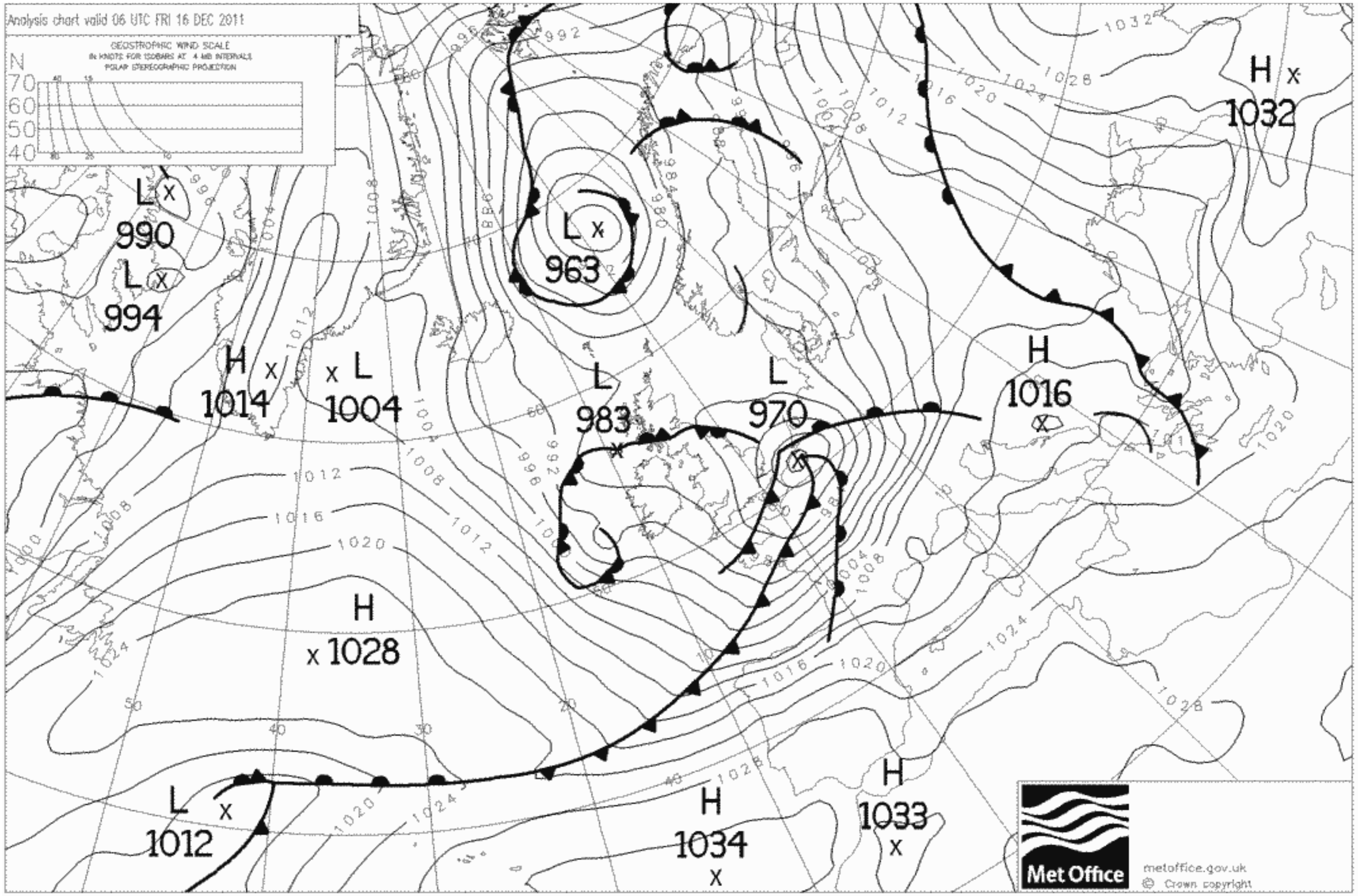




SEAKEEPING AND POWERING ALONG A ROUTE:

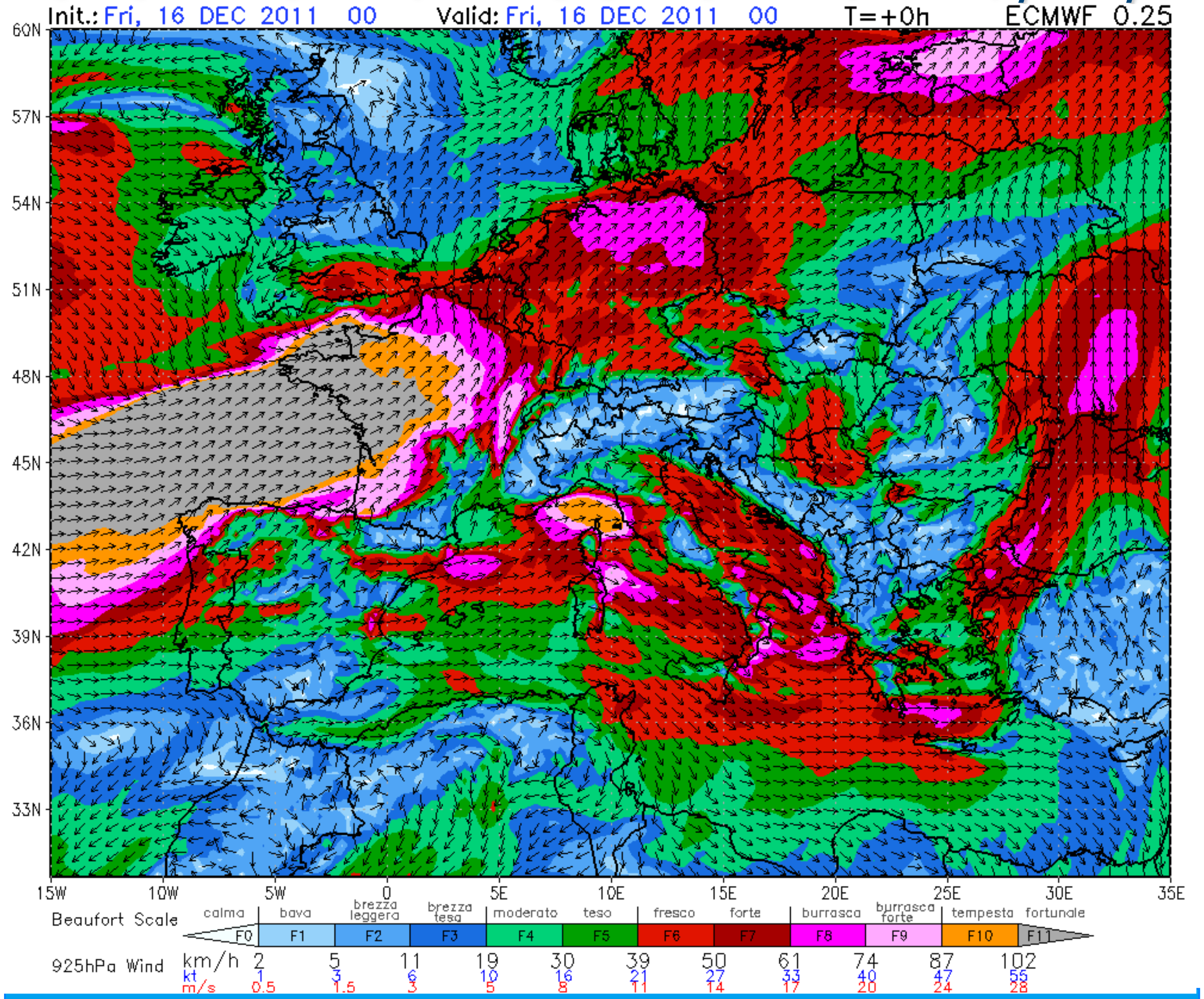
THE S175 CONTAINERSHIP

CASE STUDY: SYNOPTIC SITUATION 16/12/2011



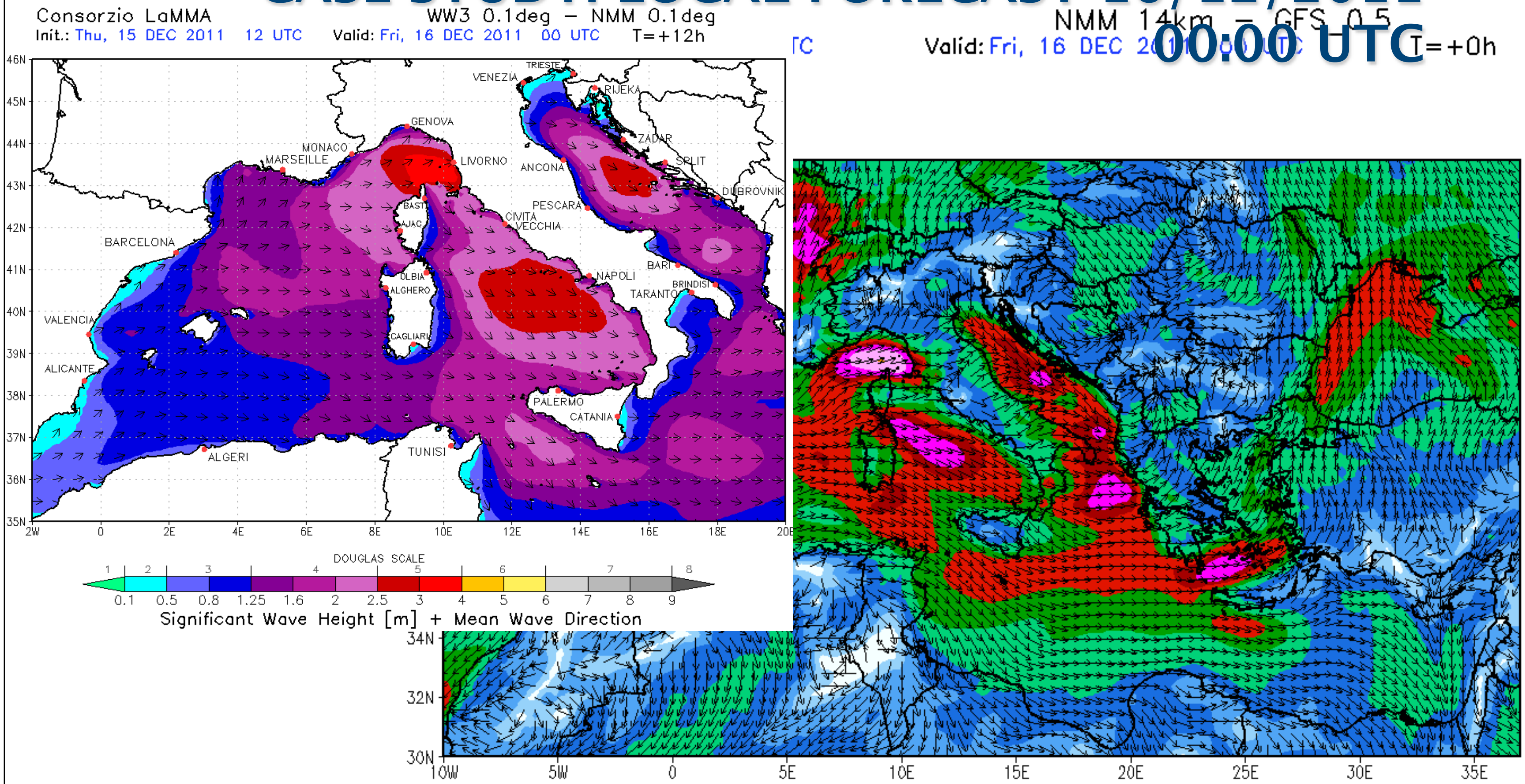
ISOBARS AND FRONTS – UK MET OFFICE

CASE STUDY: SYNOPTIC SITUATION 16/12/2011

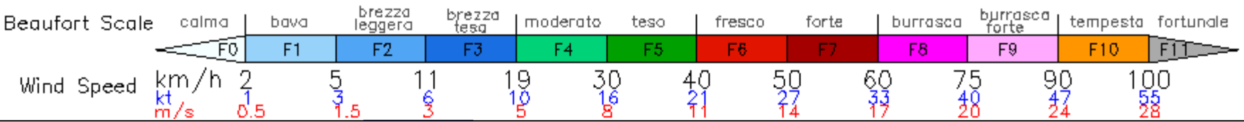


WINDS 925 hPa – GLOBAL MODEL ECMWF

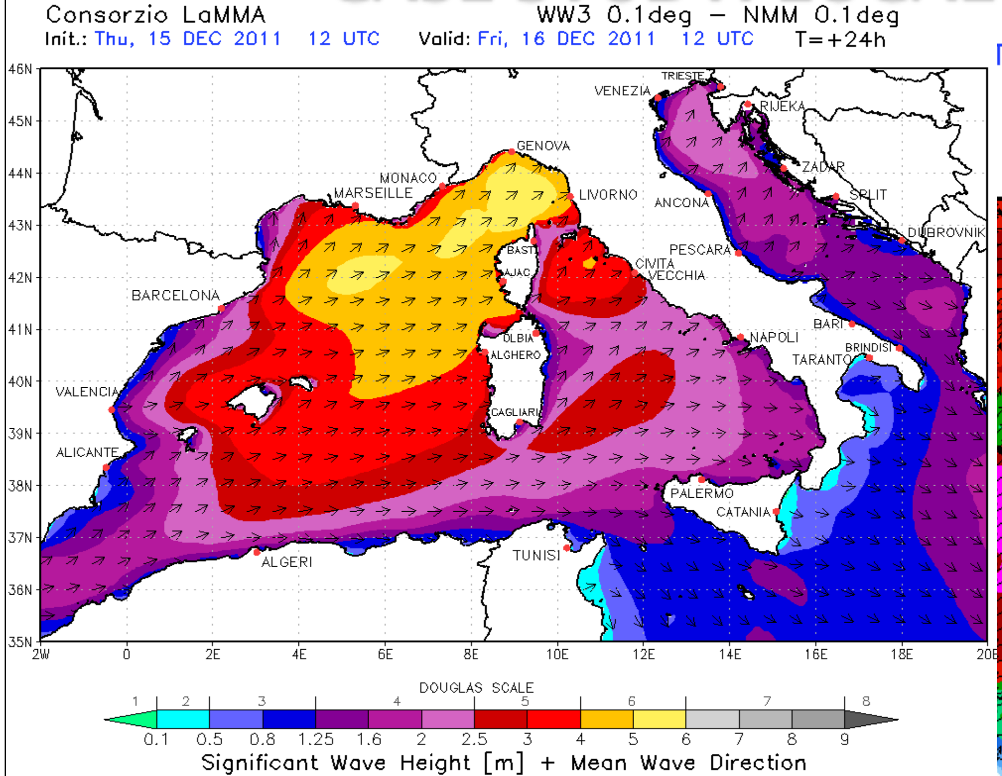
CASE STUDY: LOCAL FORECAST 16/12/2011 00:00 UTC

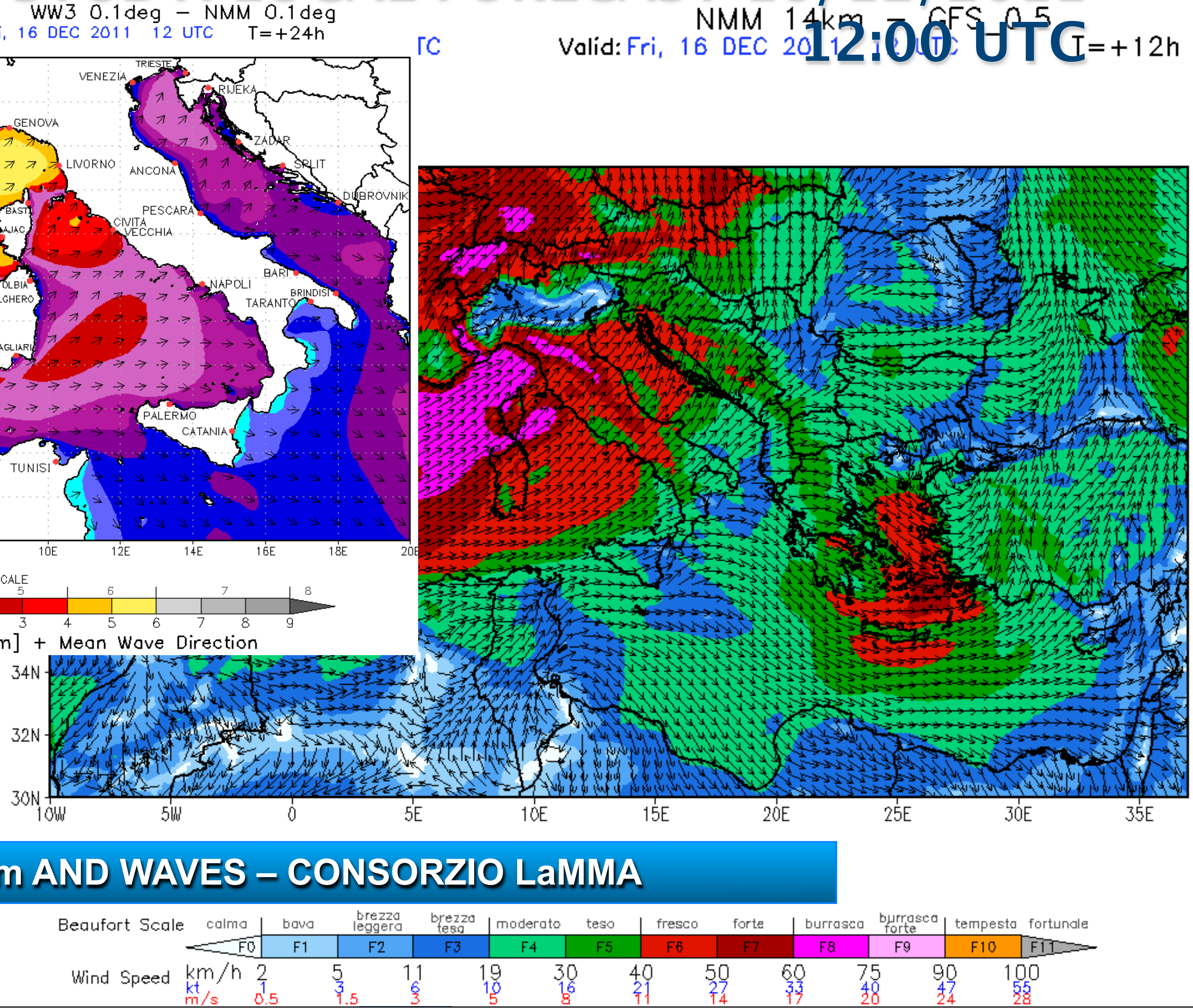


WIND 10 m AND WAVES – CONSORZIO LaMMA



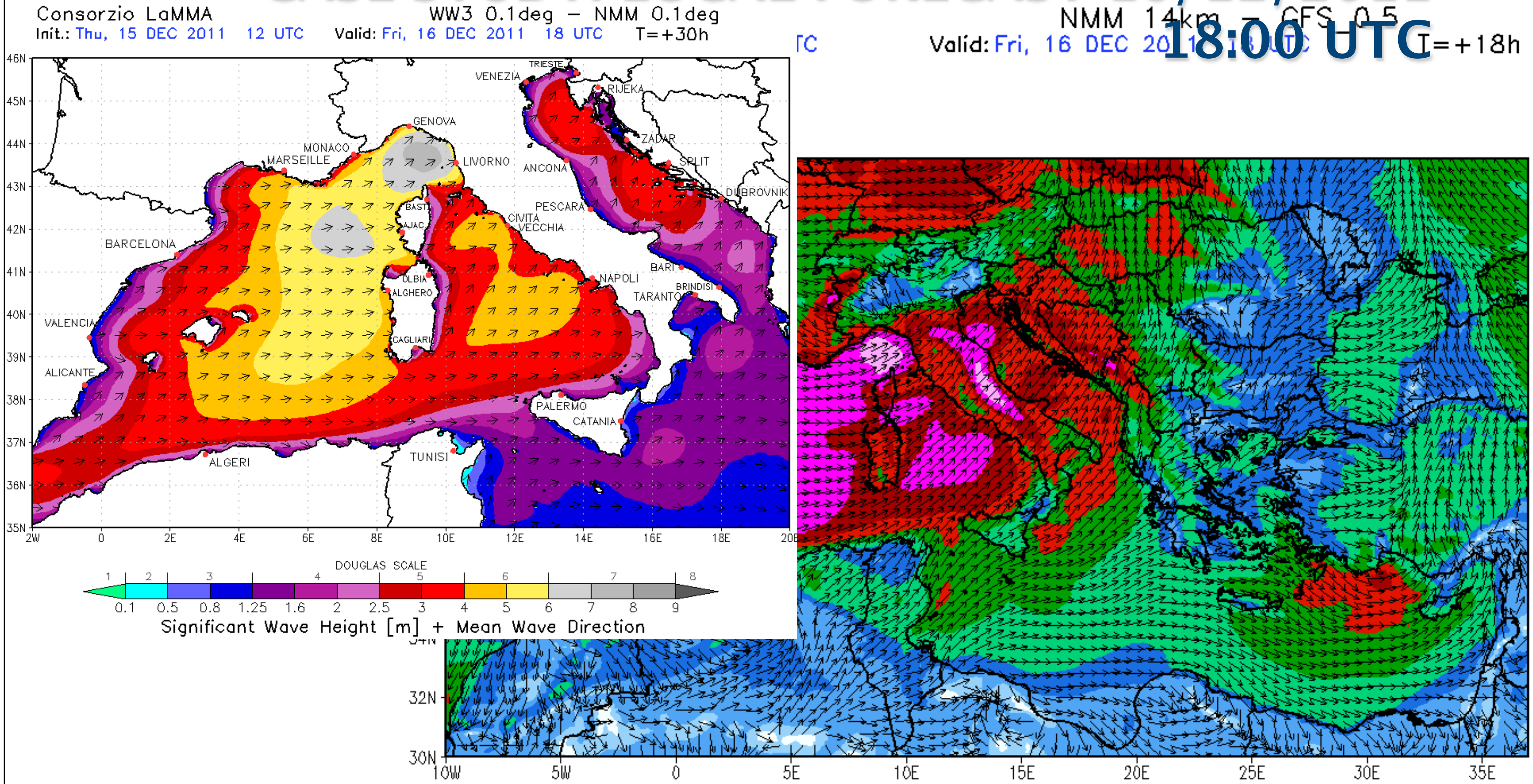
CASE STUDY: LOCAL FORECAST 16/12/2011 12:00 UTC



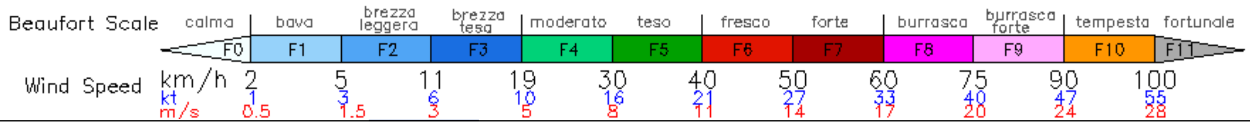


WIND 10 m AND WAVES – CONSORZIO LaMMA

CASE STUDY: LOCAL FORECAST 16/12/2011 18:00 UTC

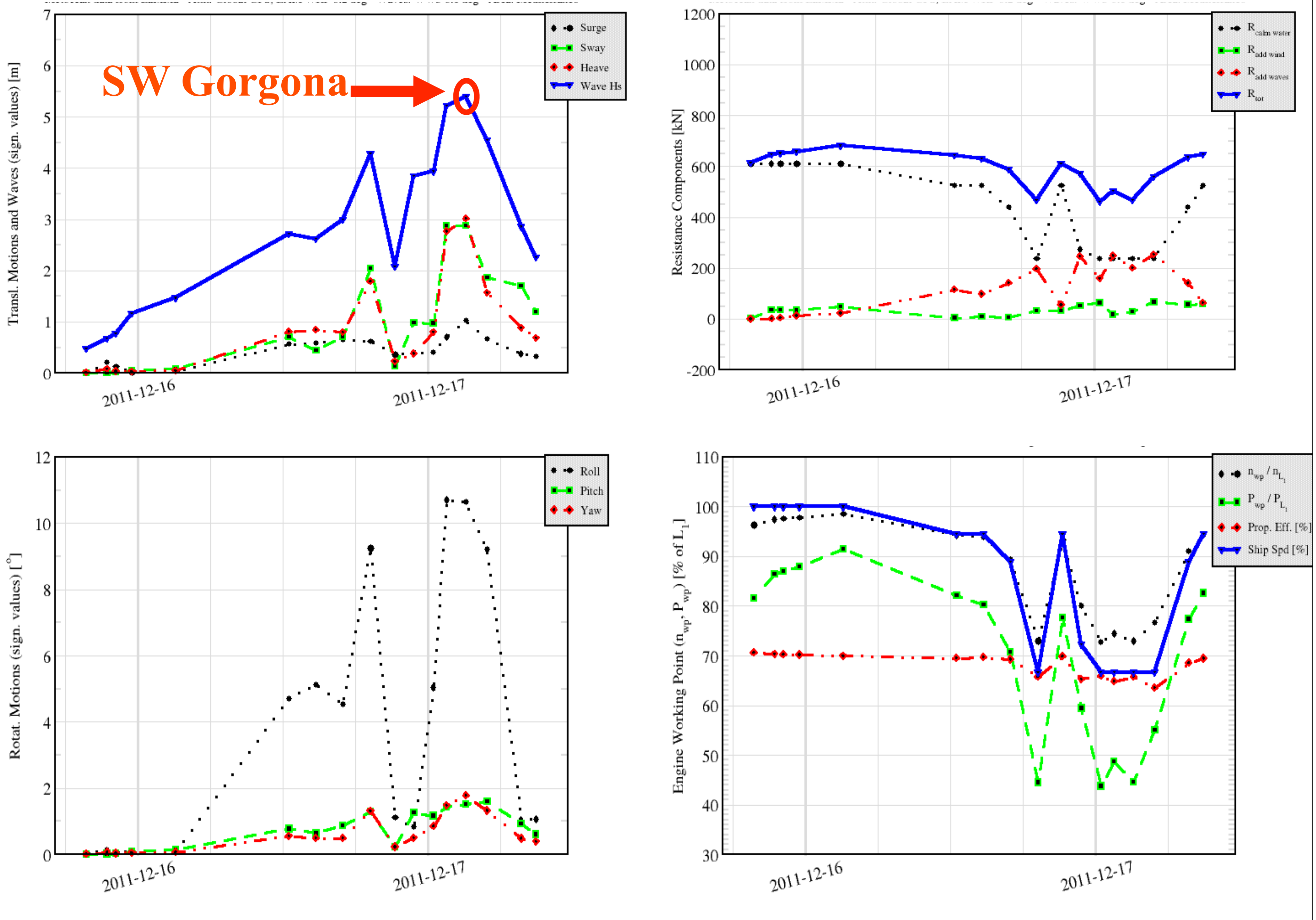


WIND 10 m AND WAVES – CONSORZIO LaMMA

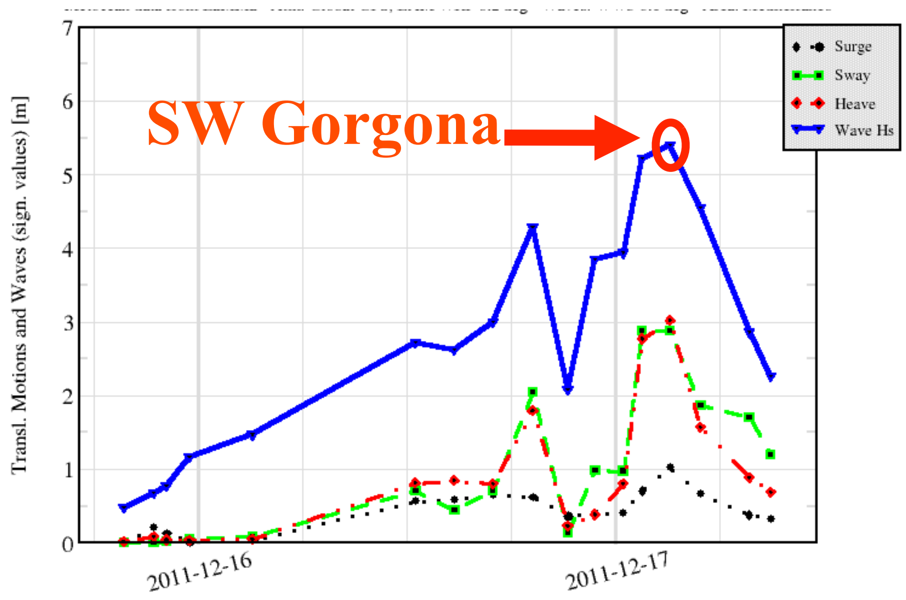


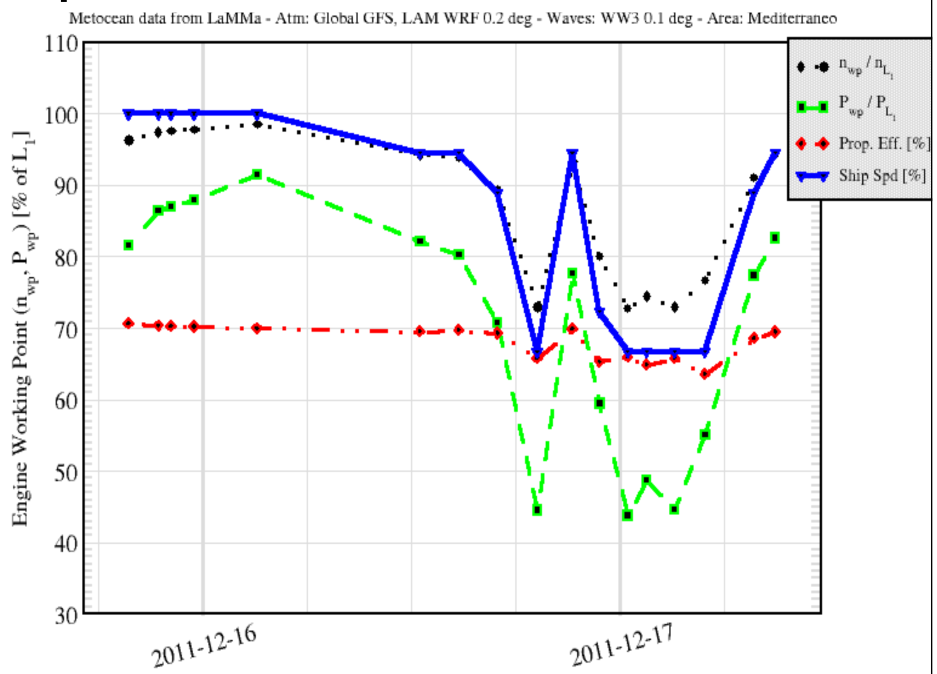
SEAKEEPING AND POWERING ALONG A ROUTE:

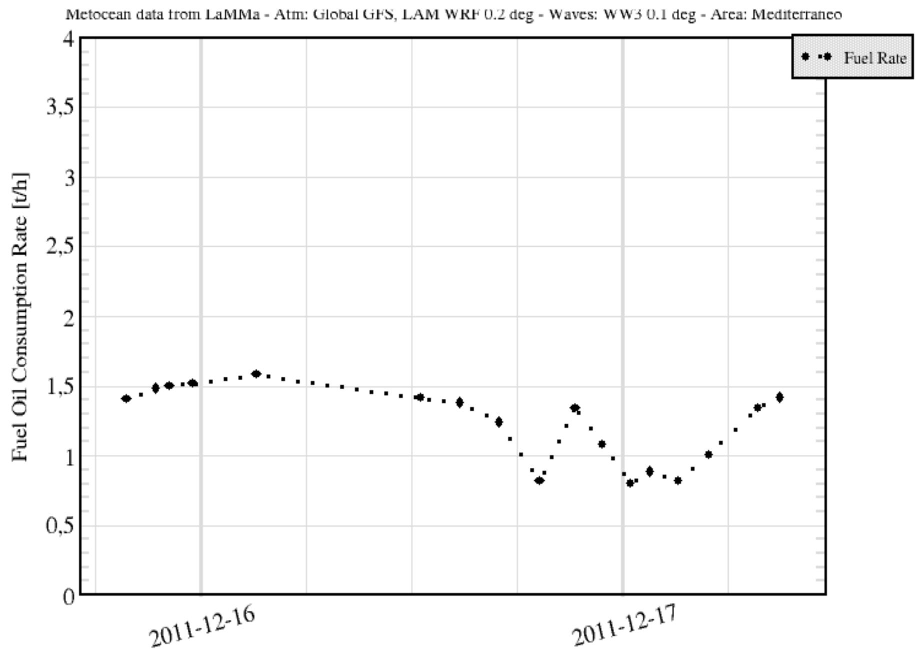
Route A – Dep. Time: 2011/12/15 20:00 UTC - Max speed: 18 KN

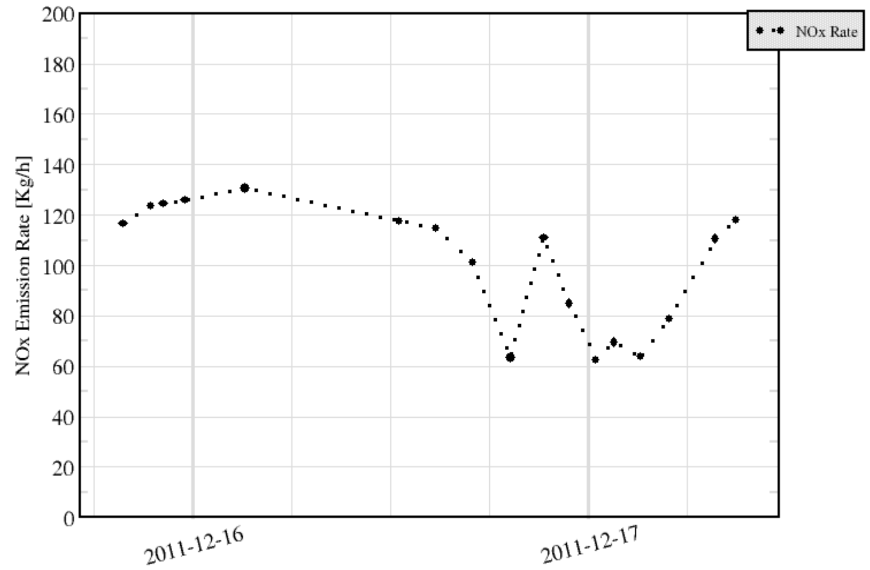


Route A – Dep. Time: 2011/12/15 20:00 UTC - Max speed: 18 KN

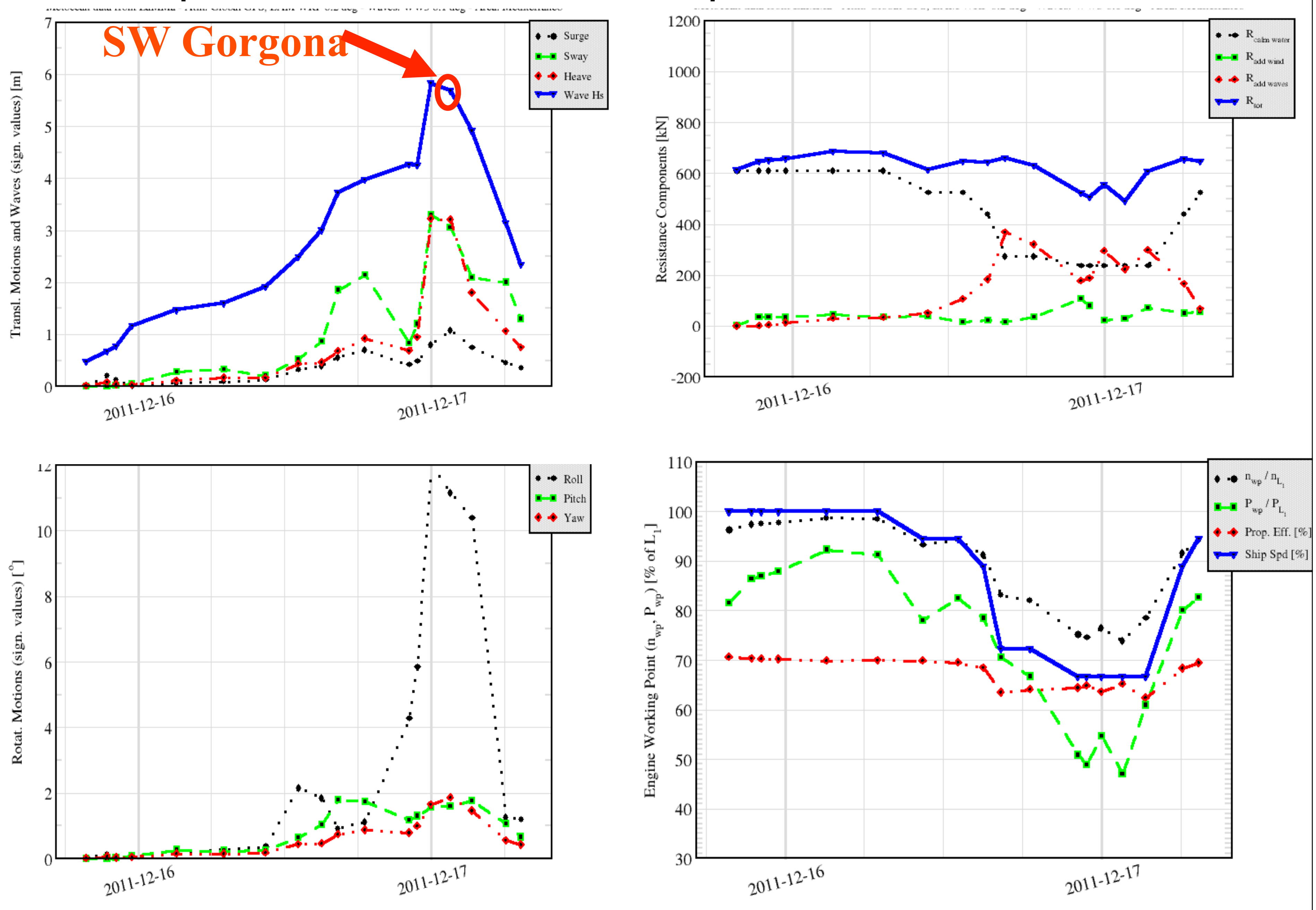




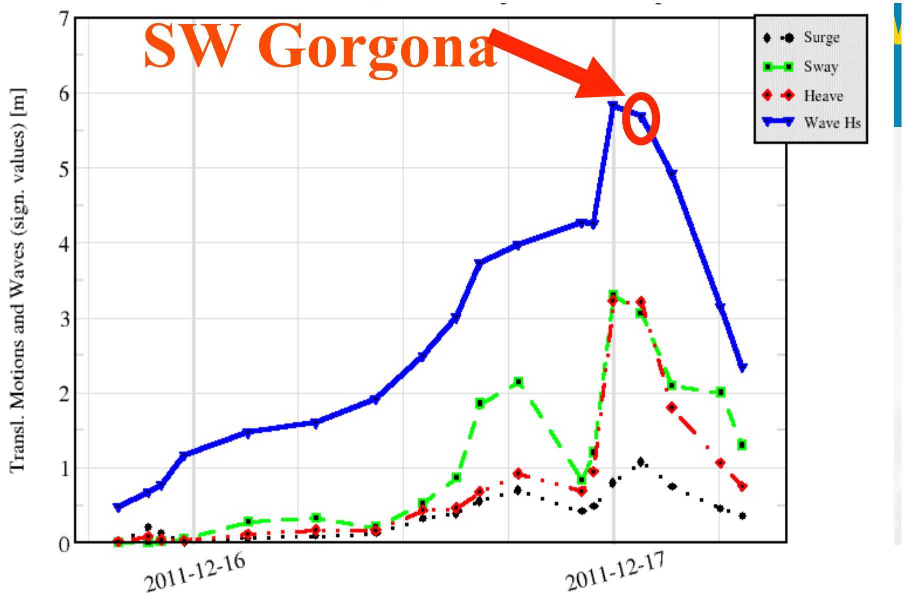


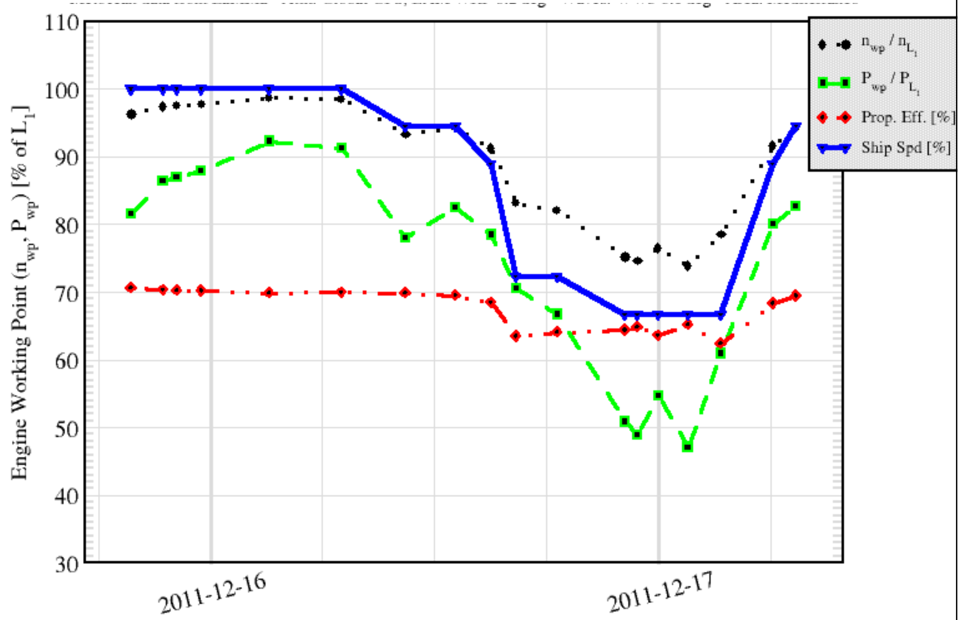


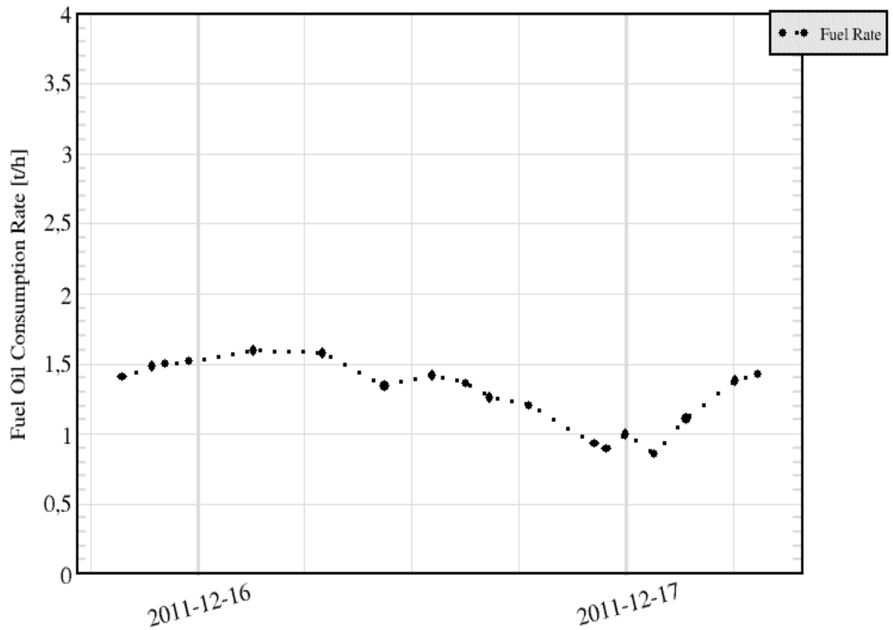
Route B – Dep. Time: 2011/12/15 20:00 UTC - Max speed: 18 KN

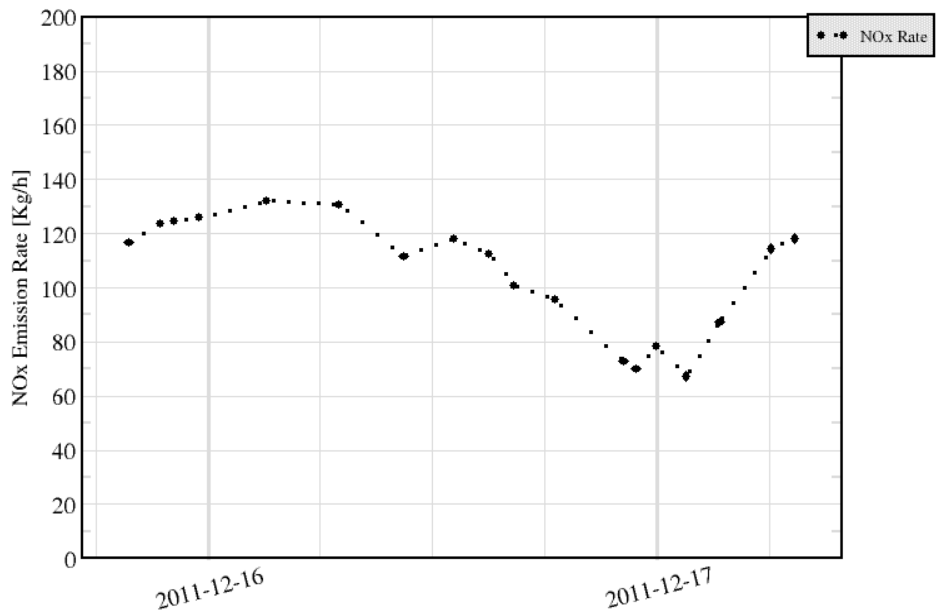


Route B – Dep. Time: 2011/12/15 20:00 UTC - Max speed: 18 KN

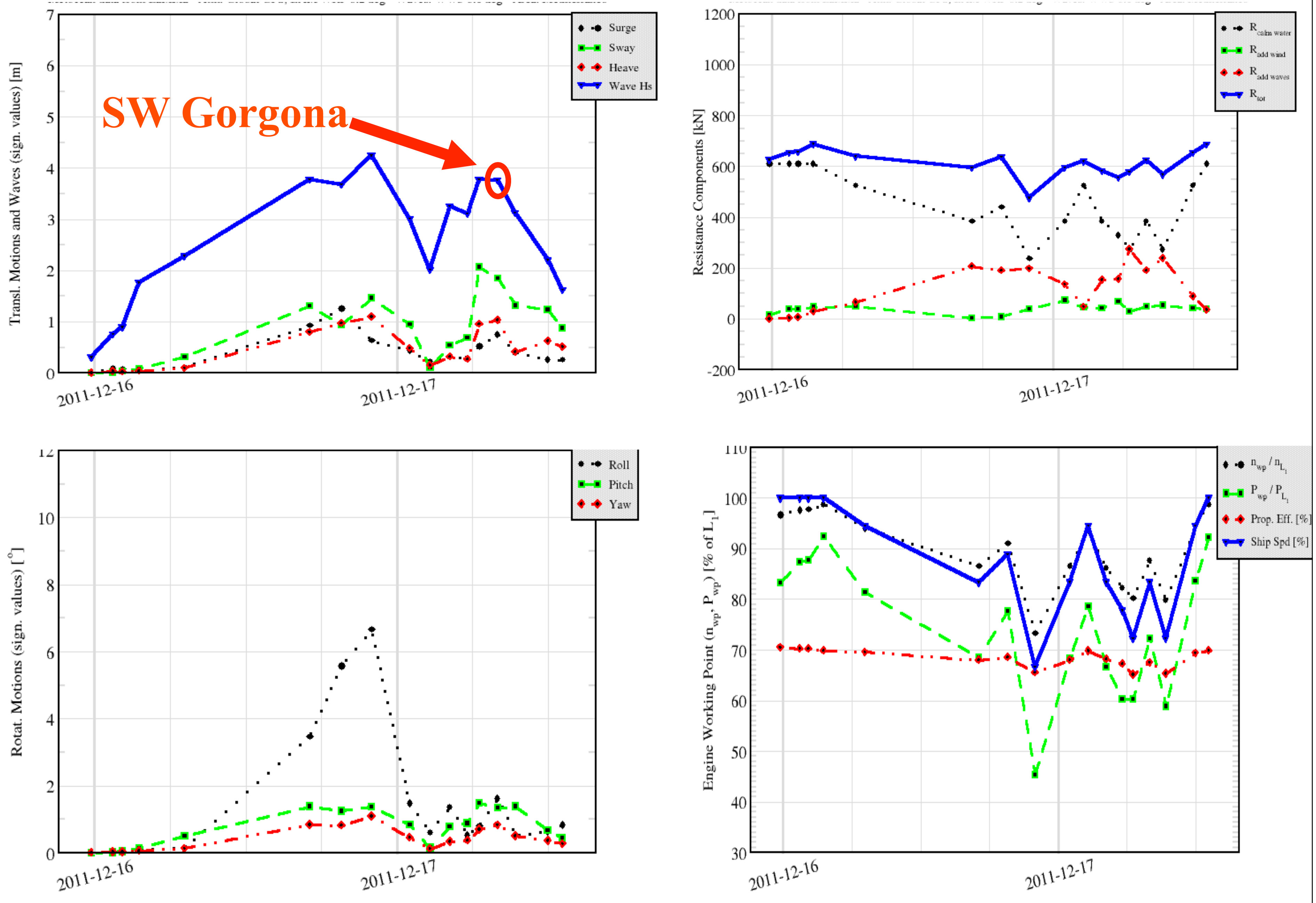




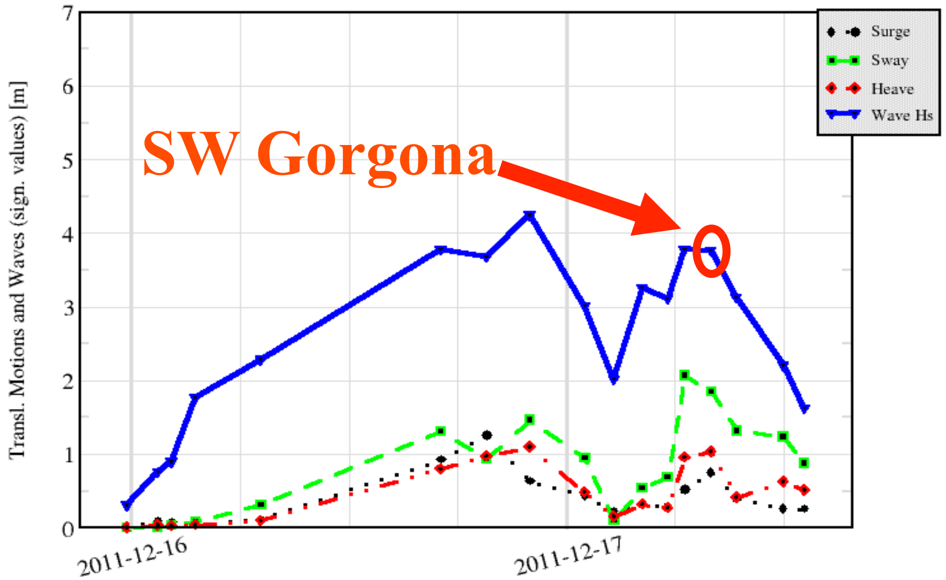


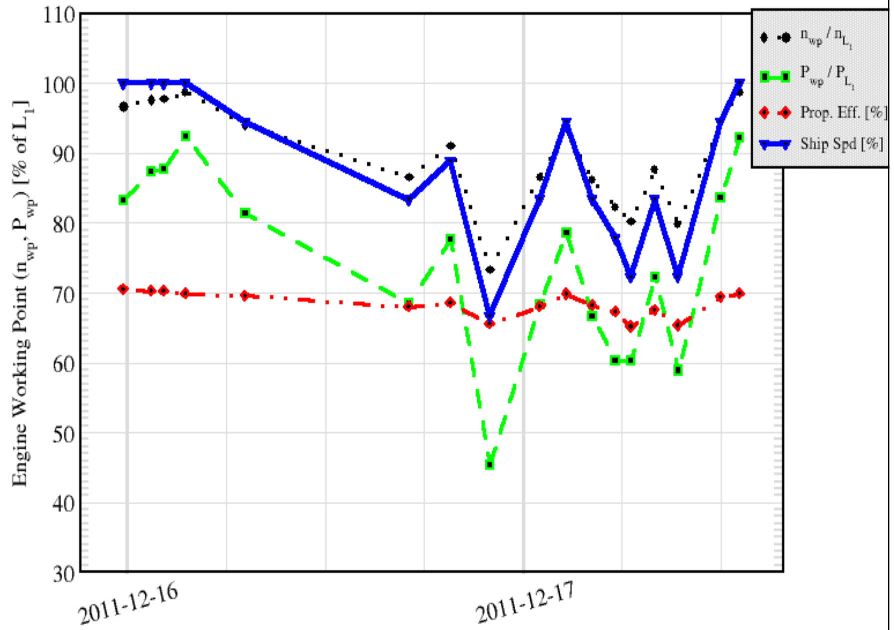


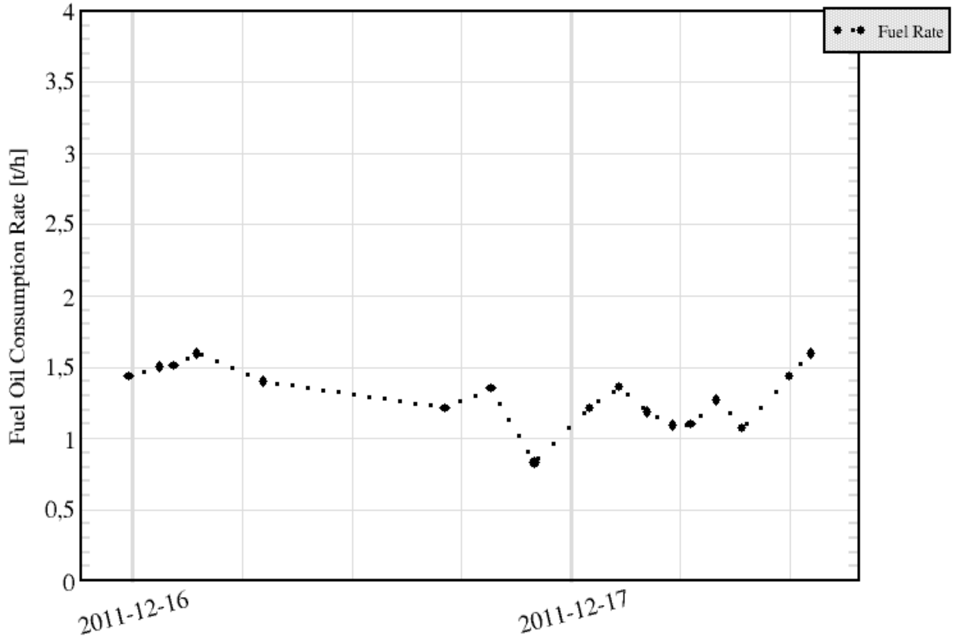
Route A – Dep. Time: 2011/12/16 00:00 UTC - Max speed: 18 KN

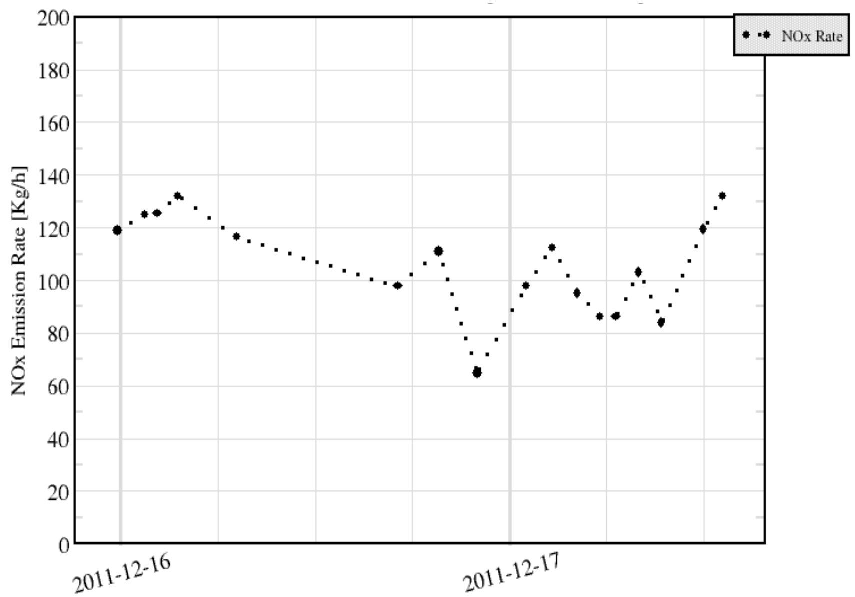


Route A – Dep. Time: 2011/12/16 00:00 UTC - Max speed: 18 KN









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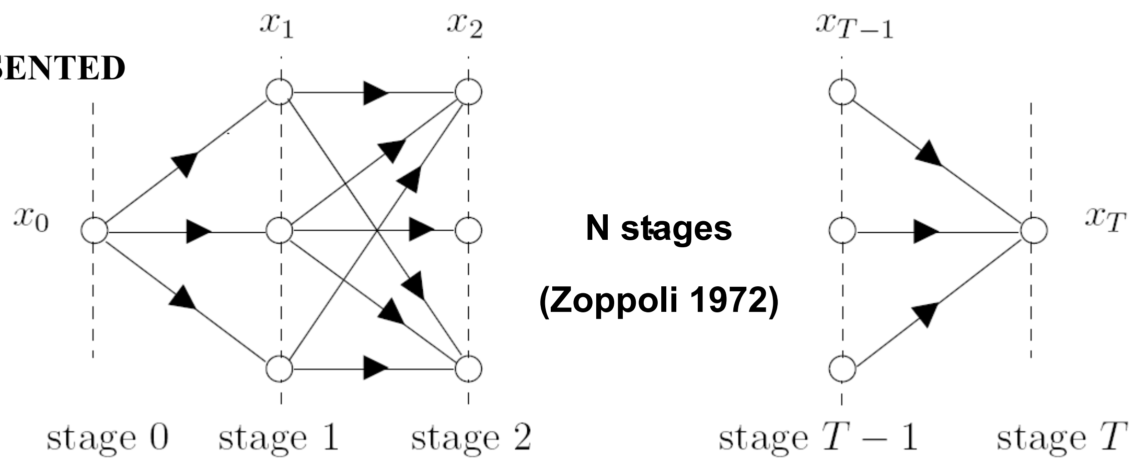
SHIP ROUTE OPTIMIZATION:
AN OPTIMAL CONTROL PROBLEM

THE ROUTES ARE REPRESENTED

IN TERMS OF AN

ORIENTED GRAPH



I = COST FUNCTION, I.E. A FUNCTIONAL TO BE MINIMIZED

$$I = h(\mathbf{x}(t_f), t_f) + \int_{t_0}^{t_f} \mathcal{L}(\mathbf{x}(t), \mathbf{u}(t), t)\,dt$$

X(t) = GENERIC ROUTE

U(t) = CONTROL VARIABLES

TYPICALLY

SHIP SPEED AND COURSE ANGLE

SYSTEM DYNAMICS

$$\dot{\mathbf{x}}(t) = \mathbf{f}(\mathbf{x}(t), \mathbf{u}(t), t)$$

$$\mathbf{x}(t) \in X, \quad \mathbf{u}(t) \in U$$

$$\mathbf{x}(t_0) = \mathbf{x}_0$$

SHIP ROUTE OPTIMIZATION:

AN OPTIMAL CONTROL PROBLEM

OPTIMIZATION CRITERIA (IN COST FUNCTION OR AS CONSTRAINTS):

- MINIMIZE FUEL CONSUMPTION AND POLLUTTANTS EMISSIONS
- OPTIMIZE SPEED AND ARRIVAL TIMES
- AVOID EXCESSVE ACCELERATIONS FOR PEOPLE AND CARGO
- REDUCE RISK OF STRUCTURAL DAMAGE
  - SLAMMING AND WHIPPING
  - GREEN WATER ON DECK
  - PROPELLER EMERGENCE AND RACING
- AVOID DANGEROUS PHENOMENA IN ADVERSE WEATHER
  - RESONANT AND PRAMETRIC ROLL
  - SURFRIDING AND BROACHING
  - PURE LOSS OF STABILITY