Virtual testbed for naval hydrodynamic problems

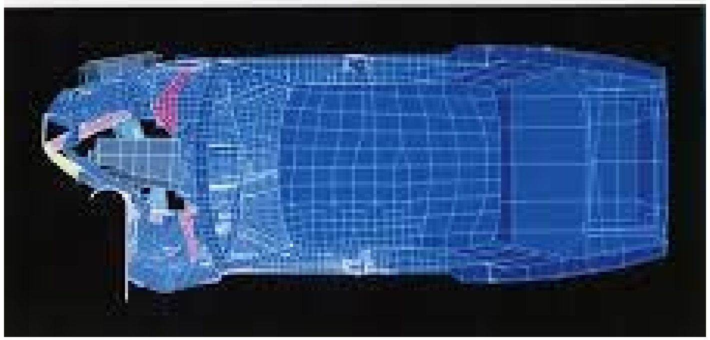
St.Petersburg State University

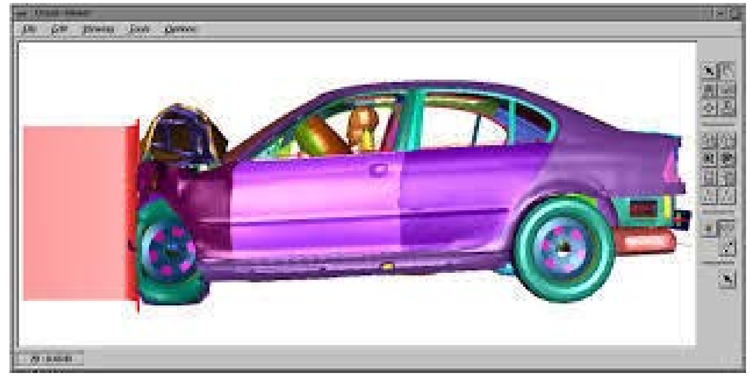
Alexander Degtyarev
Alexander Bogdanov
Vladimir Korkhov
Ivan Gankevich

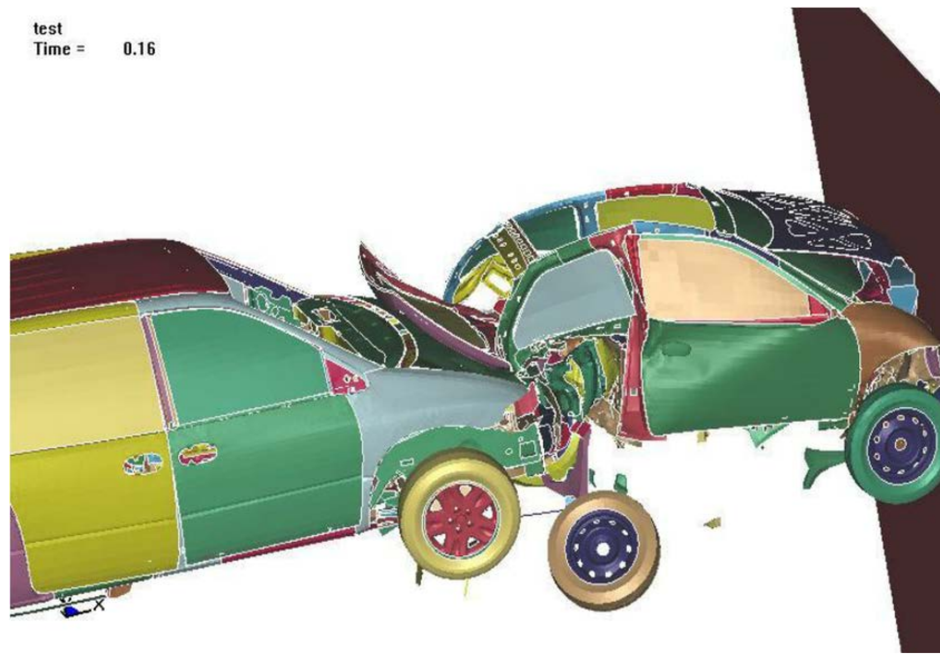
Engineering company «NEOTECH MARINE»

Yury Pylnev
Anatoly Eibozhenko

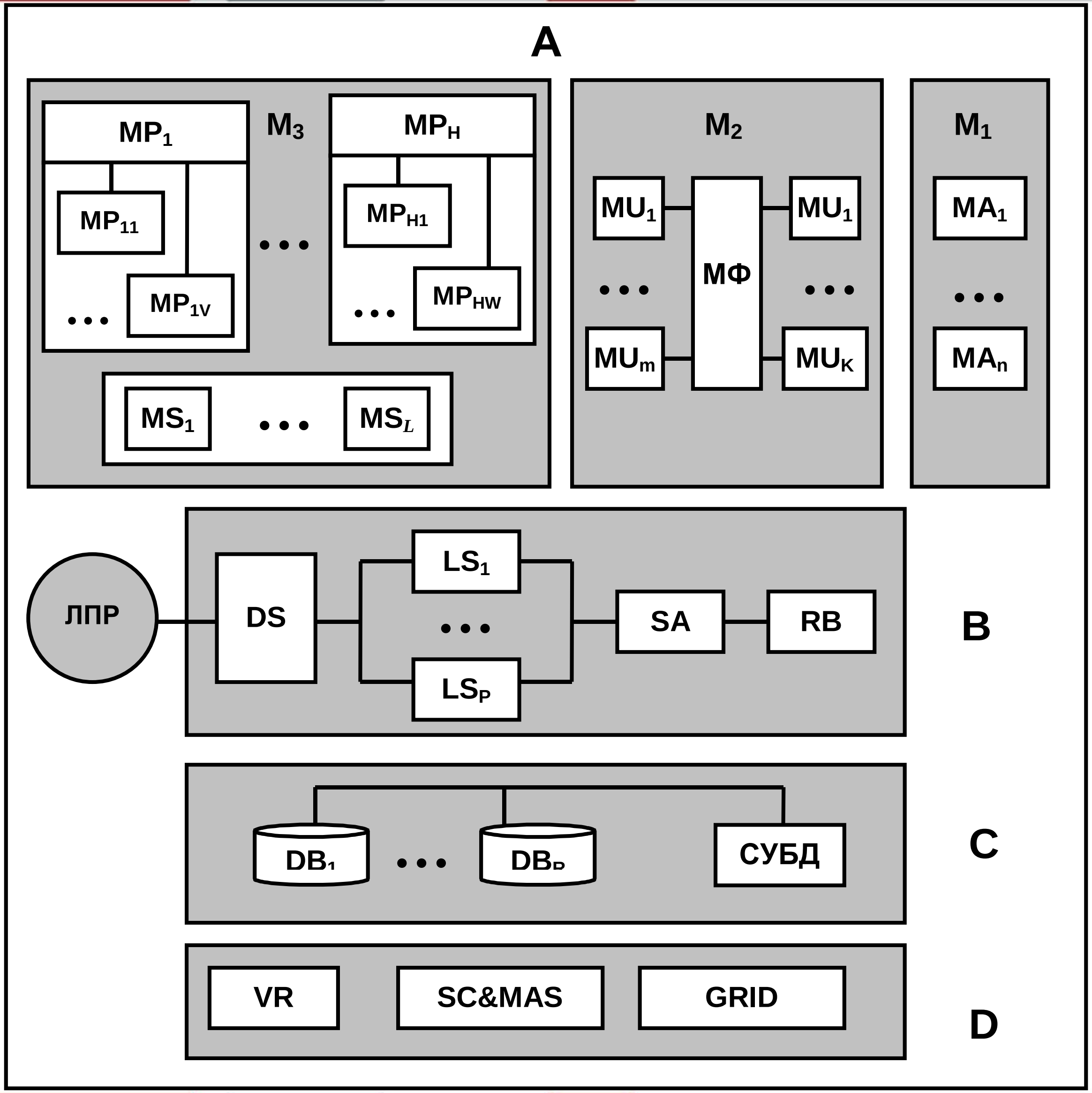
Crash simulation







Structure of virtual testbed



VT – virtual analog of real life

- Design – CAD/CAM/CAE systems + direct computer simulation
- Production – design systems + ERP systems
- Life cycle of the product – PDM system + electronic archive
- Exploitation and control – full scale simulator + on-board intelligence systems
- Etc.

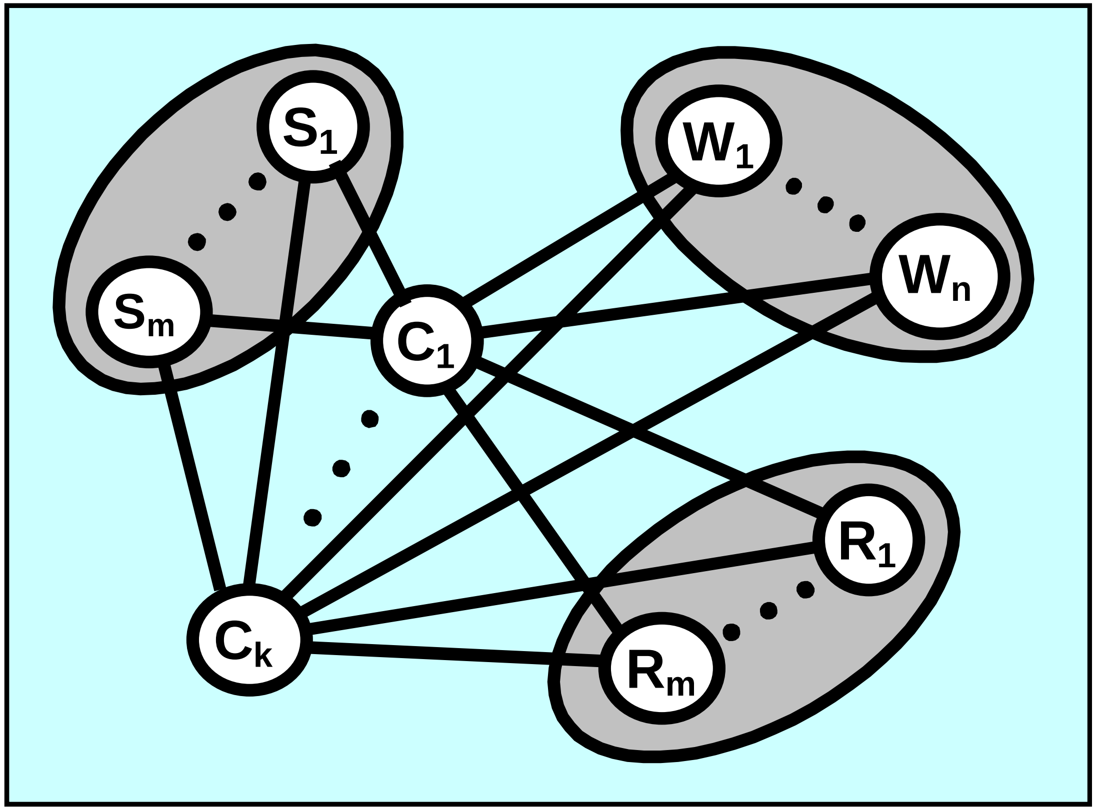
The main aspects of VT

- Computing machinery – hardware
- Uniform information field – GRID, middleware
- Program repository – libraries
- System integration – principles of testbed operation
- Concept of real time systems

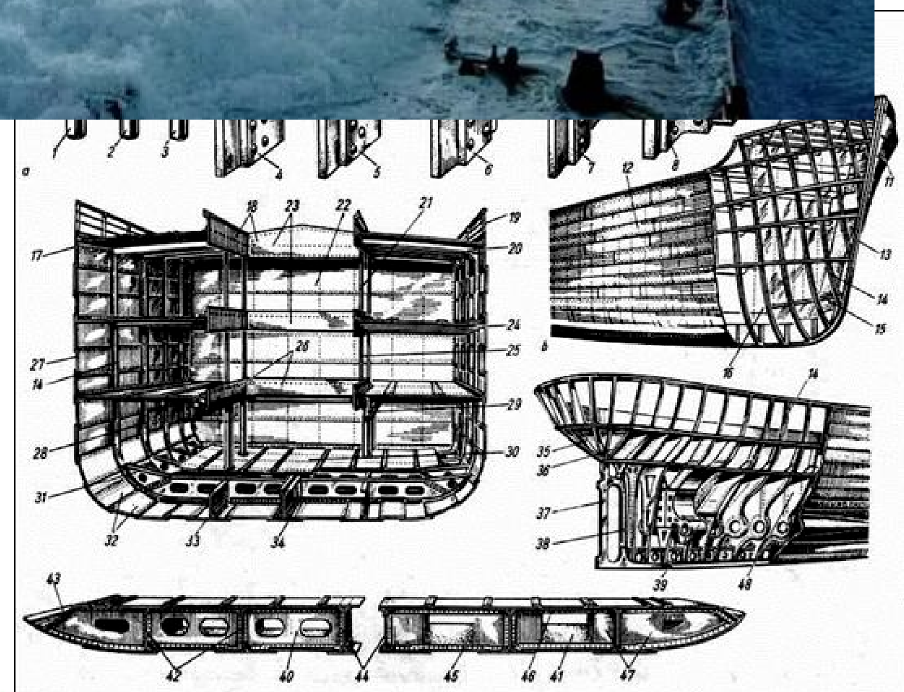
Functional aspects of VT

- Complex modelling environment (hierarchies of mathematical models)
- Scenarios (environment, missions, etc.)
- Computer technologies
- Information subsystem (DB, KB, AI)
- Data processing in multiprocessor system

Scenarios



S – set of scenarios
W – set of variants
R – set of conclusions
C – set of links
Nodes of net – frames that implement instances of sets S,W,R,C



Characteristics of marine object

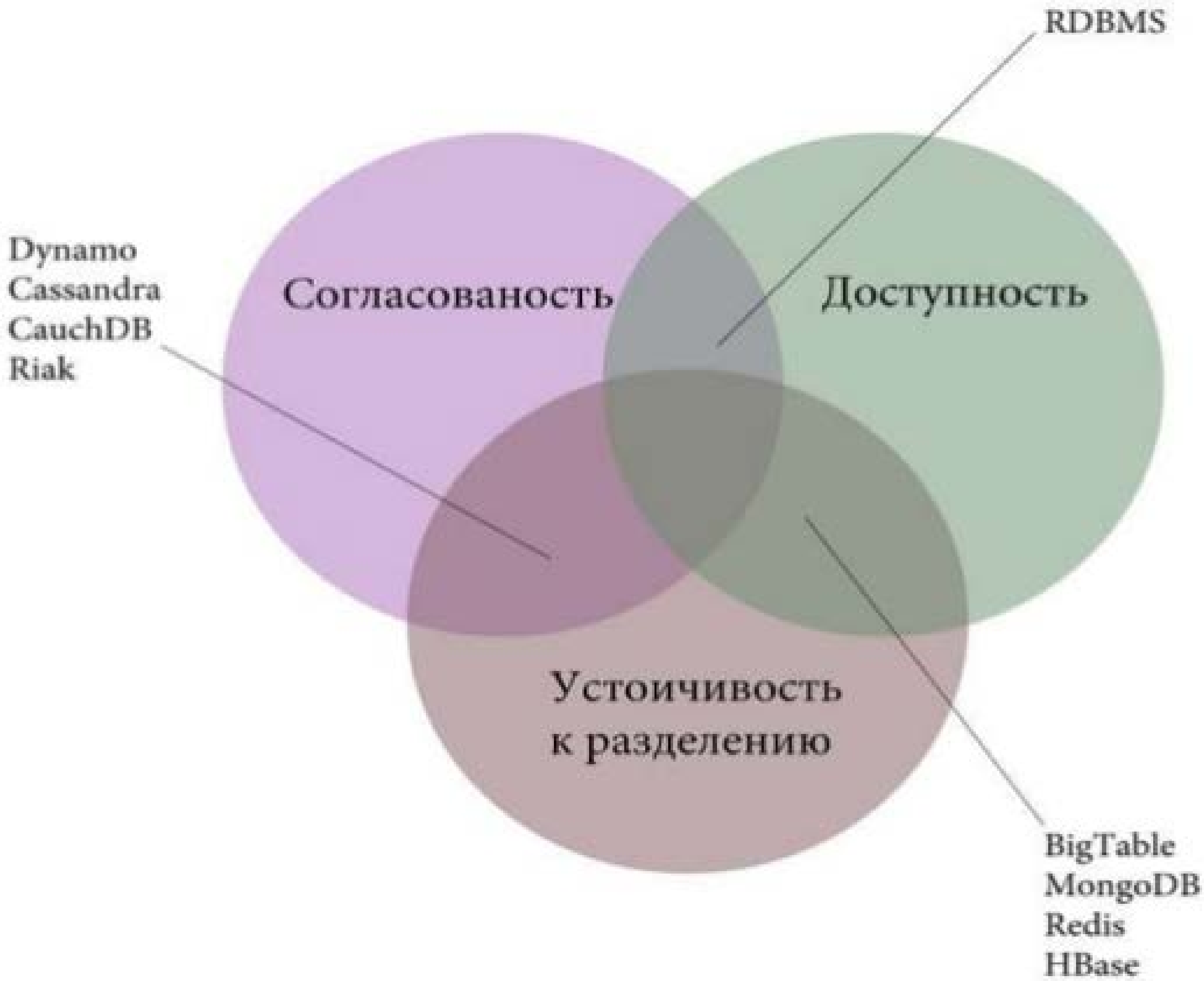
- A lot of components
- Different and heterogeneous components, complicated relations between them
- Uncertainty of operating conditions and external excitations
- Numerous scenarios and options for control
- …….

Characteristics of complex problem

- **Data processing**
- **Calculations**

Preprocessing,
Processing,
Postprocessing

CAP theorem data realizations



Scenarios
new approach to environment problem formulation

Wave climate - A seaway characterization determined primarily from climatic wave spectra obtained at a particular geographic location. It is characterized by parametric and other properties of the local climatic wave spectra and by the associated probability density distribution of $h_{1/3}$.

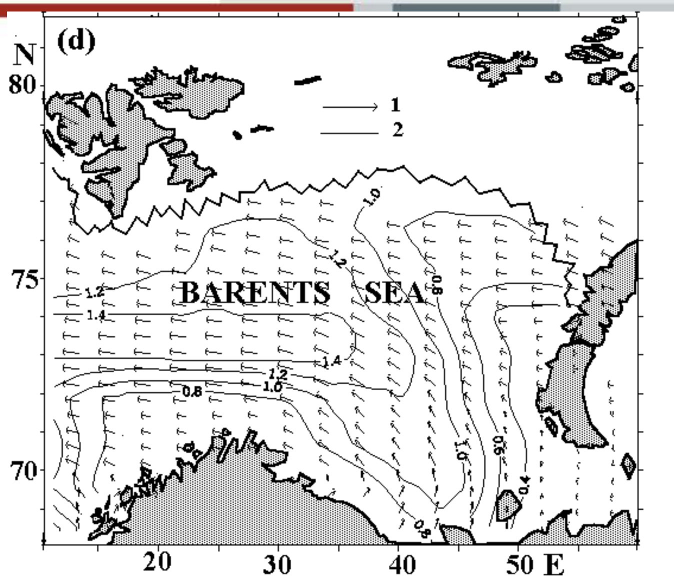
XVIII IMO Assembly (1993)

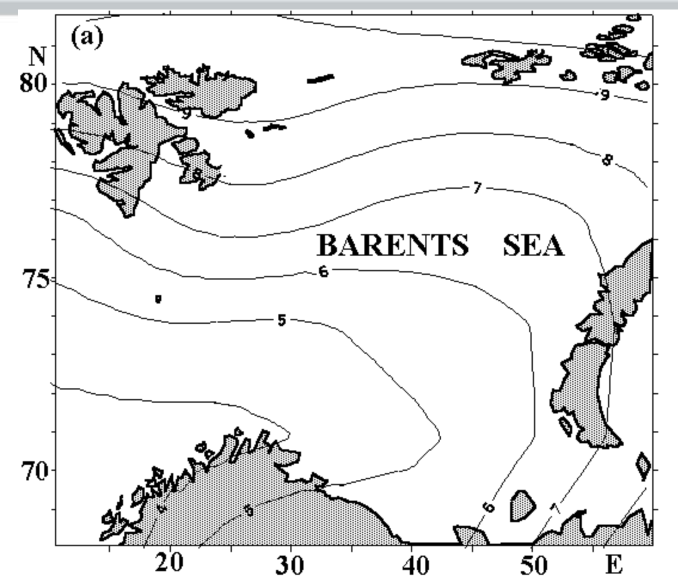
$$\left\{\Xi(\vec{r},t),\vec{V}(\vec{r},t)\right\} \longleftrightarrow S(\omega,\Theta,\vec{r},t)$$

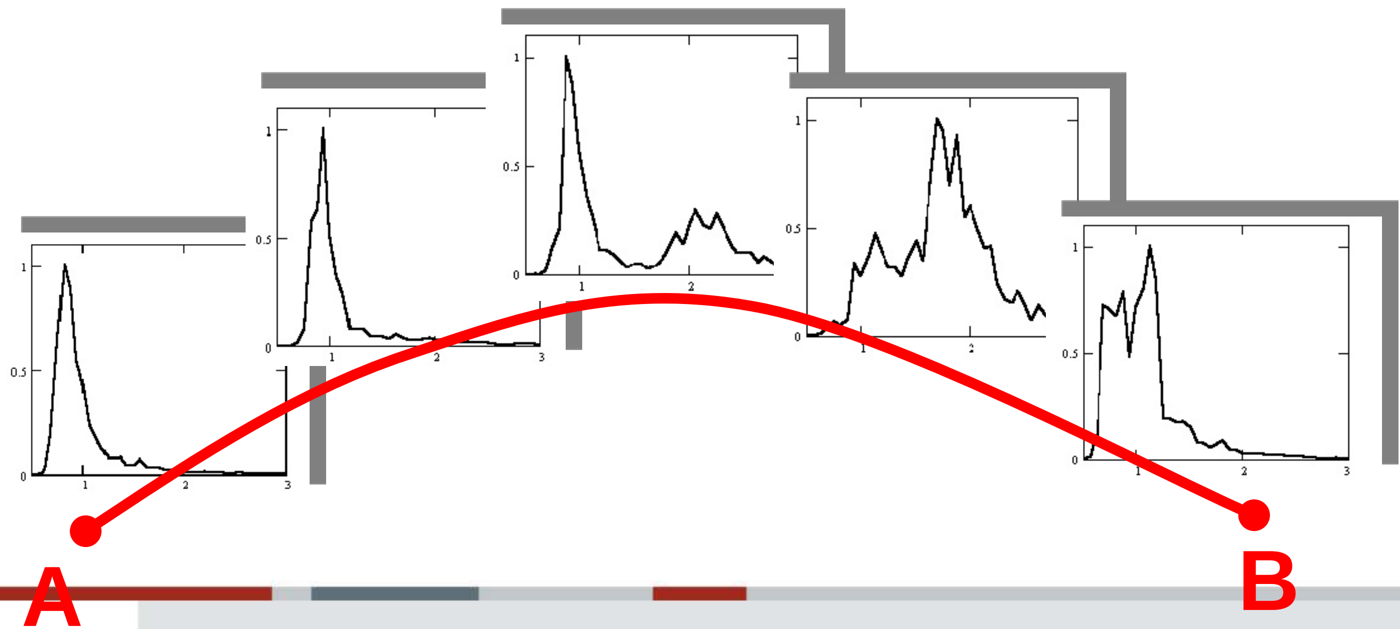
$$\vec{r} \to \{x_i, y_j\}$$

$$t \to \{t_k\}$$

“Wave weather scenario”


(d)
N
80
75
70
20
30
40
50 E
1
2
BARENTS SEA


(a)
N
80
75
70
20
30
40
50
E
BARENTS SEA


A
B

Traditional approach

- Significant wave height
- Spectrum type
- Additional spectral parameters
- Course angle of general radiation of wave system

Wave weather scenarios approach

- Peculiarities of wave making conditions ;
- Geographical peculiarities of considered region;
- Changeableness of hydro meteorological conditions;
- Scenarios of synoptic changeableness;
- Characteristics of season changeableness;
- Long term presence of the ship in considered region or in some diapason of exploitation conditions.

The list of wave scenarios

- short term scenario,
- stormy scenario,
- scenario « mission»,
- scenario «navigation»,
- scenario «life time»

Basis of weather scenarios modeling

Synoptic variability simulation

$$S(\omega,\Theta,\vec{r},t) = S(\omega,\Theta,\Xi). \quad \Xi = \Xi(\vec{r},t)$$

$$\Xi(r,t) = \{h_W, h_S, \tau_W, \tau_S, \Theta_W, \Theta_S\}$$

$$\Xi(x,y,t) = \sum_k \alpha_k(t)\Psi_k(x,y) \quad \int K_\Xi(\vec{r}_1,\vec{r}_2)\Psi_k(\vec{r}_2)d\vec{r}_2 = \lambda_k \Psi_k(\vec{r}_1)$$

$$A_t = \sum_k \Phi_k A_{t-k} + E_t$$

$$\vec{V}(x,y,t) = \sum_k \beta_k(t)\vec{\Psi}_k(x,y)$$

$$\int K_{UU}(\vec{r}_1,\vec{r}_2)\Psi_U(\vec{r}_2)d\vec{r}_2 + \int K_{UV}(\vec{r}_1,\vec{r}_2)\Psi_V(\vec{r}_2)d\vec{r}_2 = \lambda\Psi_U(\vec{r}_1)$$

$$\int K_{VU}(\vec{r}_1,\vec{r}_2)\Psi_U(\vec{r}_2)d\vec{r}_2 + \int K_{VV}(\vec{r}_1,\vec{r}_2)\Psi_V(\vec{r}_2)d\vec{r}_2 = \lambda\Psi_V(\vec{r}_1)$$

Simulation procedure

$$\left\{\Xi\left(\vec{r},t\right),\vec{V}\left(\vec{r},t\right)\right\}\longleftrightarrow S\left(\omega,\Theta,\vec{r},t\right)$$

1. Reproduction of spectrum parameters

$$\Xi\left(x,y,t\right)=\sum_k \alpha_k(t)\Psi_k\left(x,y\right)$$

2. Reproduction of wind speed parameters

$$\vec{V}\left(x,y,t\right)=\sum_k \beta_k(t)\vec{\Psi}_k\left(x,y\right)$$

3. Reproduction of the system of related time

$$A_t=\sum_k \Phi_k A_{t-k}+E_t$$

4. Generation of metocean fields
   in correspondent

$$\zeta\left(x,y,t\right)=\sum_i\sum_j\sum_k \Phi_{ijk}\zeta\left(x-i,y-j,t-k\right)+\varepsilon\left(x,y,t\right)$$

Reproduction of spatial-time wave surface field ζ(x, y, t)

$$\varsigma(x,y,t)=\sum_n c_n\cos(u_n x+v_n y-\omega_n t+\varepsilon_n)$$

$$\left[\prod_{k=1}^{N} L_k\right]\varsigma(\vec v)=\left[\prod_{k=1}^{N} Q_k\right]\varepsilon(\vec v)$$

$$L_k=\sum_{j=1}^{N_k} l_j^{[k]}\frac{\partial^j}{\partial x^j}$$

$$Q_k=\sum_{j=1}^{P_k} q_j^{[k]}\frac{\partial^j}{\partial x^j}$$

$$S_\varsigma(\vec\omega)=\frac{1}{(2\pi)^N}\frac{\left|\sum_{j_1=0}^{P_1}\ldots(N)\ldots\sum_{j_n=0}^{P_n} C_{[j_1\ldots j_n]}\, i^{\sum_m j_m}\prod_{k=1}^{N}\omega_k^{j_k}\right|^2}{\left|\sum_{j_1=0}^{N_1}\ldots(N)\ldots\sum_{j_n=0}^{N_n} B_{[j_1\ldots j_n]}\, i^{\sum_m j_m}\prod_{k=1}^{N}\omega_k^{j_k}\right|^2}$$

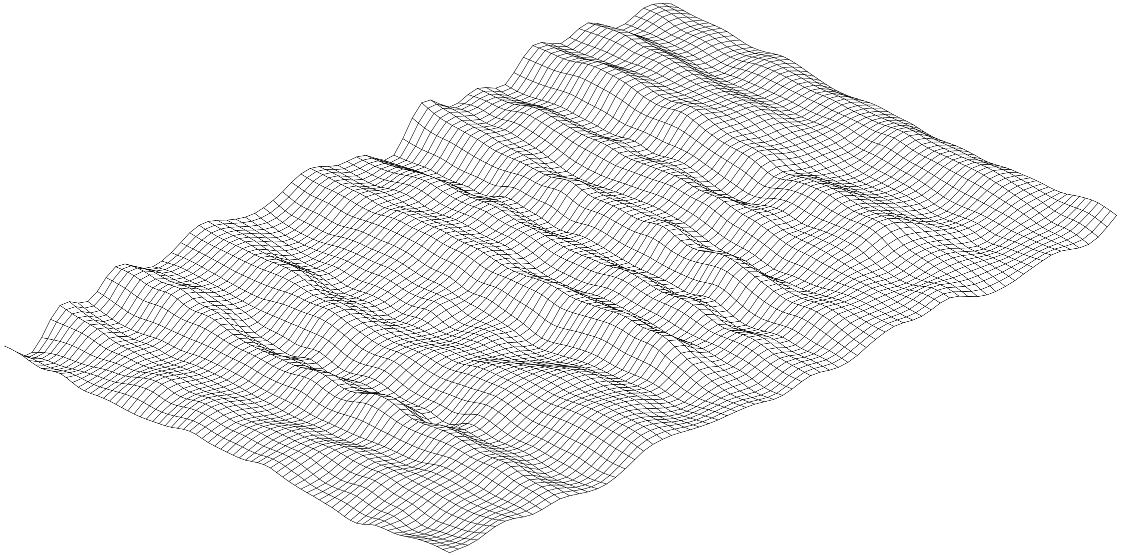
$$\varsigma_{\vec v}=\sum_{j_1=0}^{N_1}\ldots(N)\ldots\sum_{j_n=0}^{N_n}\Theta_{\vec j}\,\varsigma_{\vec v-\vec j}+\varepsilon_{\vec v}$$

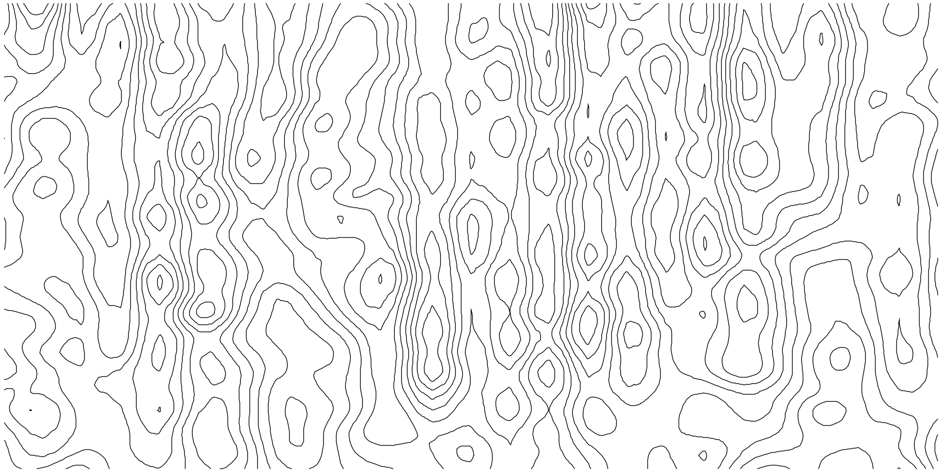
$$\varsigma_{(x,y,t)}=\sum_{i=0}^{N_x}\sum_{j=0}^{N_y}\sum_{k=0}^{N_t}\Theta_{(i,j,k)}\varsigma_{(x-i,y-j,t-k)}+\varepsilon_{(x,y,t)}$$

$$\sigma_\varepsilon^2=D[\varsigma]-\sum_{i=0}^{N_x}\sum_{j=0}^{N_y}\sum_{k=0}^{N_t}\Theta_{(i,j,k)}K_\varsigma(i\Delta_x, j\Delta_y, k\Delta_t)$$

$$K_\varsigma(x,y,\tau)=\sum_{i=0}^{N_x}\sum_{j=0}^{N_y}\sum_{k=0}^{N_t}\Theta_{(i,j,k)}K_\varsigma(x-i\Delta_x, y-j\Delta_y, \tau-k\Delta_t)$$

Example of 3D waves simulation





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Wave scenario modeling

$$S(\omega,\beta)=S(\omega,\beta;\ \Xi)$$

Necessary to solve the following problems:

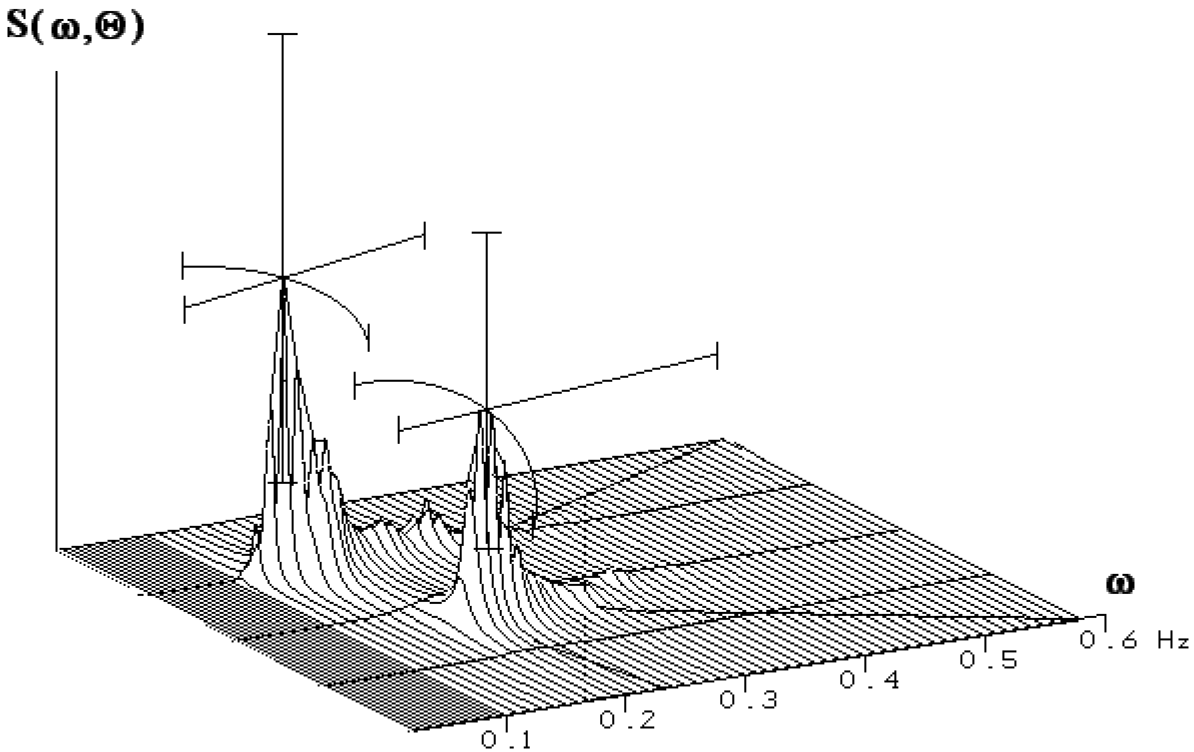
- Spectra parameterization $S(\omega,\beta)$ (in space Ξ).
- Separation of uniform classes of spectra.
- Takeoff stable states $S(\omega,\beta,x,y,t)$ in time t and (or) space (x,y)

$$S(\omega,\beta)=m_{00}\sum_{p=1}^{N}\gamma_p S_p(\omega,\beta\,|\,\omega_{\max},\beta_{\max})$$

Example of functional field: Directional spectrum of sea waves

$$S(\omega,\Theta) = S(\omega,\Theta,\Xi)$$

Ξ – *parameters set*



Climatic spectrum of complex sea.
NE–region of Black Sea

Probabilistic model of consecution of storms and calm weather

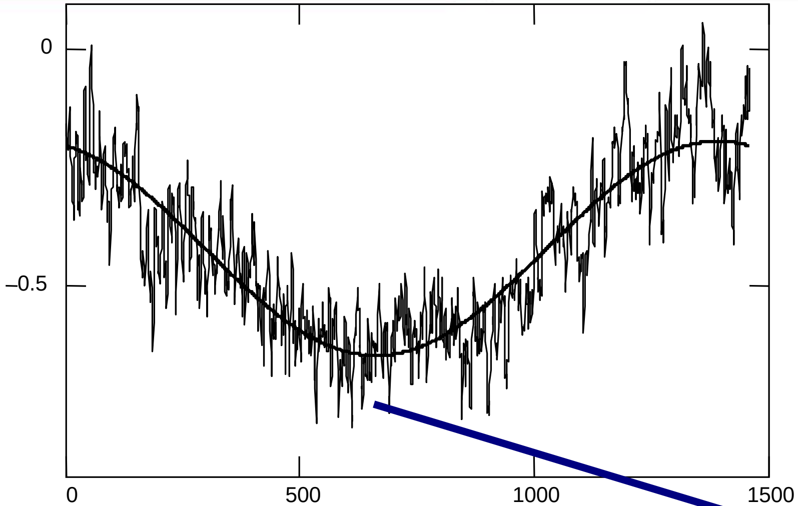
$$\xi(t) = \sum_{k=1}^{n} w_k\left(z, t - \sum_{j=1}^{k-1}\left(\tau_j + \Theta_j\right)\right)$$

$$w(z,t) = \begin{cases} z + (h^{+} - z)u(t/\tau) & , \quad 0 \le t \le \tau \\ z - (h^{-} - z)u((t-\tau)/\theta) & , \quad \tau \le t \le \tau + \theta \\ 0 & , (t < 0)\, U\, (t > \tau + \theta \end{cases}$$

$$u(t) = \begin{cases} t/\delta \ ,0 \le t \le \delta \\ 1/(1-\delta) - t/(1-\delta), \delta \le t \le 1, \\ 0 \ ,(t<0) \cup (t>1) \end{cases}$$

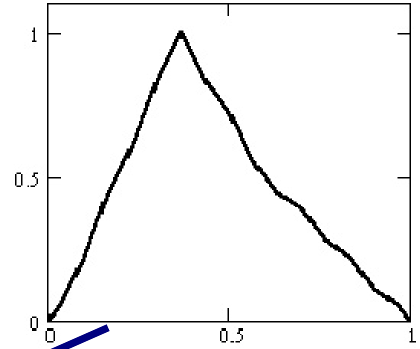
Algorithm of weather scenarios modeling

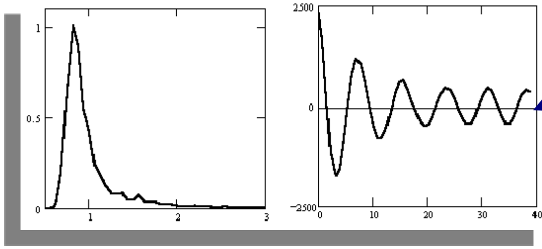
Generation of weather scenario

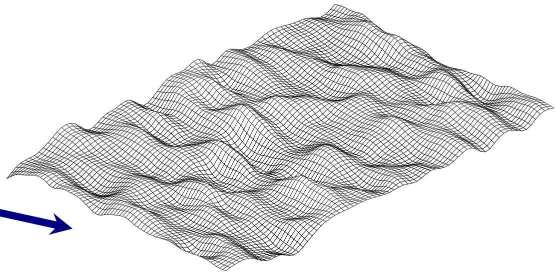


$$\tau_k = F_\tau^{-1}(\gamma_1^{(k)}), \Theta_k = F_\Theta^{-1}(\gamma_2^{(k)}),$$

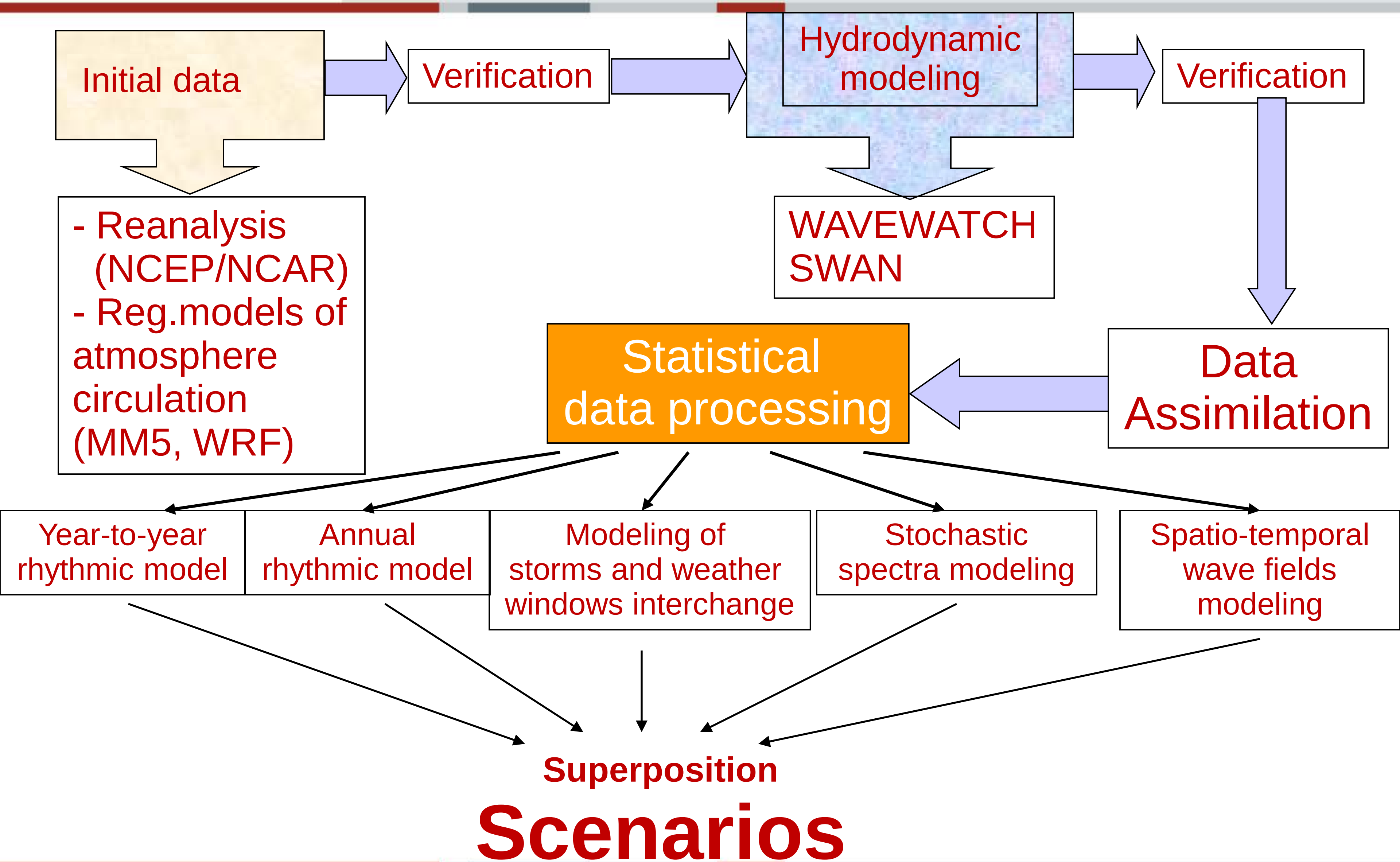
$$h_k^+ = F_{h^+|\tau}^{-1}(\gamma_3^{(k)} \mid \tau_k), h_k^- = F_{h^-|\Theta}^{-1}(\gamma_4^{(k)} \mid \Theta_k)$$

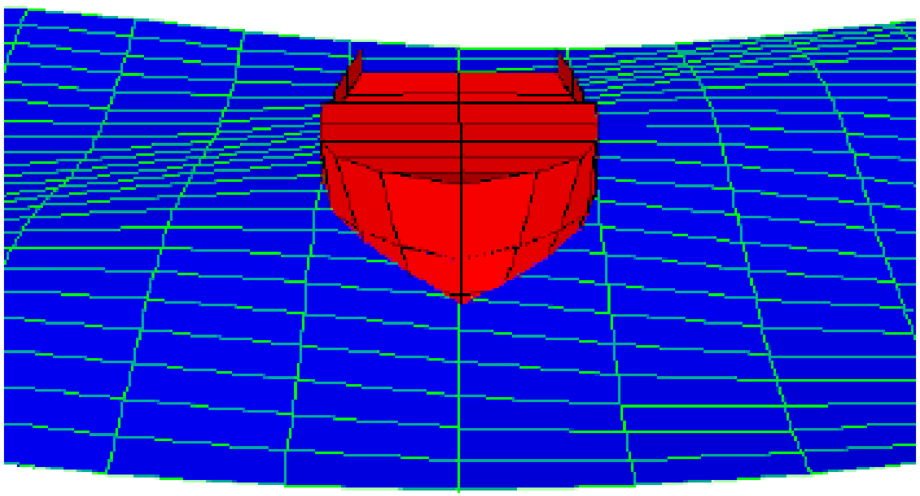


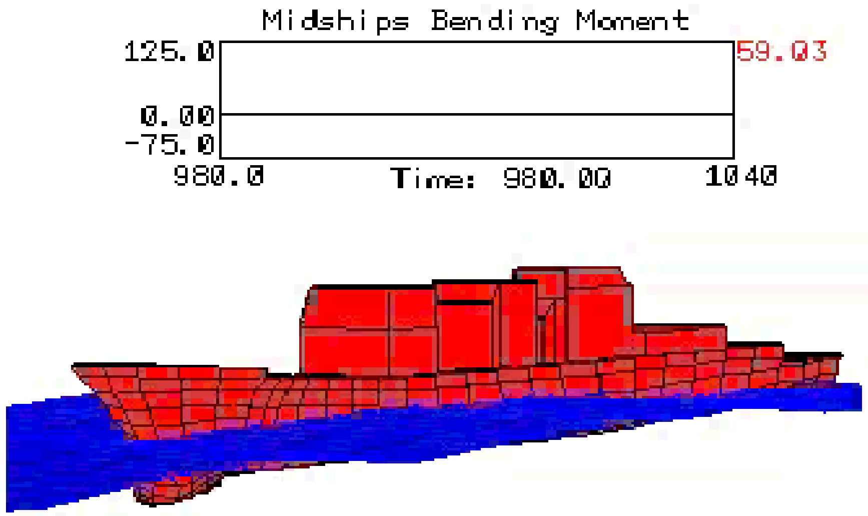


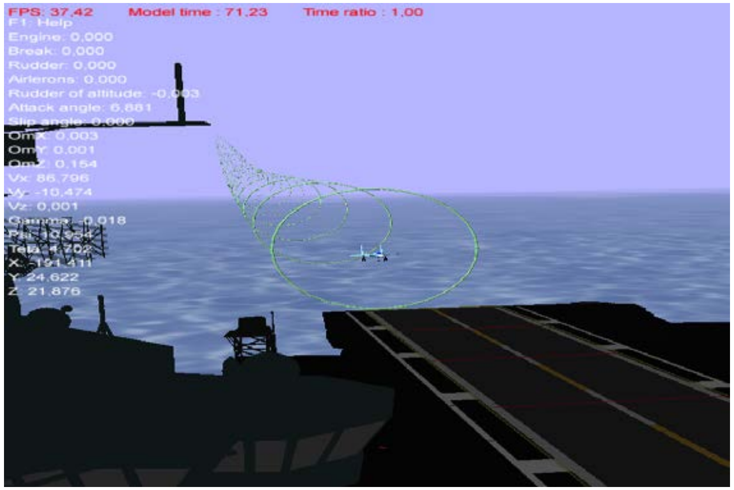


General algorithm of wave scenarios

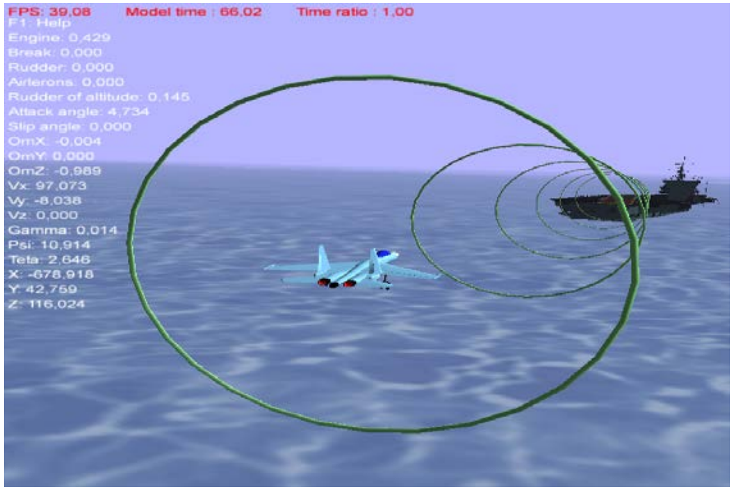





Midships Bending Moment
125.0
59.03
0.00
-75.0
980.0
Time: 980.00
1040


FPS: 37,42
Model time : 71,23
Time ratio : 1,00
F1: Help
Engine: 0,000
Break: 0,000
Rudder: 0,000
Airlerons: 0,000
Attack angle: 6,881
OmY: 0,001
Vx: 86,796
Vy: -10,474
Vz: 0,001
Gamma: -0,018
Y: 24,622
Z: 21,876


FPS: 37,71
Model time : 71,98
Time ratio : 0,10
F1: Help
Engine: 0,000
Break: 0,000
Rudder: 0,000
Airlerons: 0,000
Rudder of altitude: 0,136
Attack angle: 7,083
Slip angle: 0,000
OmX: 0,004
OmY: 0,000
OmZ: 0,417
Vx: 83,737
Vy: -10,405
Vz: 0,000
Gamma: -0,015
Z: 9,646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Model time : 66,02
Time ratio : 1,00
F1: Help
Engine: 0,429
Break: 0,000
Rudder: 0,000
Airlerons: 0,000
Rudder of altitude: 0,145
Attack angle: 4,734
Slip angle: 0,000
OmX: -0,004
OmY: 0,000
OmZ: -0,989
Vx: 97,073
Vy: -8,038
Vz: 0,000
Gamma: 0,014
Psi: 10,914
Teta: 2,646
X: -678,918
Y: 42,759
Z: 116,024


FPS: 38,00
Model time : 71,23
Time ratio : 1,00
F1: Help
Engine: 0,000
Break: 0,000
Rudder: 0,000
Airlerons: 0,000
Rudder of altitude: -0,003
Attack angle: 6,881
Slip angle: 0,000
OmX: 0,003
OmY: 0,001
OmZ: 0,154
Vx: 86,796
Vy: -10,474
Vz: 0,001
Gamma: -0,018
Psi: 10,954
Teta: 4,702
X: -191,411
Y: 24,622
Z: 21,876

Questions?