ON-LINE MODELING TECHNIQUE FOR THE OIL SPILL FATE AS APPLIED TO THE NORTHEASTERN SAKHALIN SHELF (THE FIRST INTERNET VERSION)

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Introduction

Northeastern Sakhalin shelf which oil and gas fields are actively developed has the following potential oil spill sources: appraisal wells drilled during the ice free period, oil-fields operation objects (beginning from 1999), oil terminals, oil shipments, and subsea pipelines (Fig. 1). Technique that helps to model oil spill fate in marine environment has been previously developed to obtain statistical data for the environmental impact assessment and contingency planning of the projects operating on Sakhalin shelf oil and gas fields (Kochergin *et al.* 1999a, 1999b, 2000a, 2000b). Technique of statistical modeling comprises such phases as: 1) preparation of the initial information about potential spill sources and their technical characteristics; 2) preparation and analysis of the initial hydrometeorological information for meteorological and oceanographic fields construction; 3) development of hydrometeorological scenarios; 4) modeling over the developed scenarios using trajectory and physical-chemical models of oil spill fate: 5) statistical processing of the results.

Putting the first oil&gas production complex “Vityaz” into operation on the Sakhalin shelf in 1999 made it necessary to assess the oil spills in real time. At present there are different approaches developed to on-line modeling of oil spills in the potentially dangerous marine areas, for example, “OSCAR” system (Aamo *et al.*, 1997), “OSIS” (Rusin *et al.*, 1997), Meteo-France model “MOTHY” (Soares dos Santos & Daniel, 2000), and oil spill quick response system for the Sea of Japan (Varlamov *et al.*, 2001), *etc.* As for on-line modeling technique described below it was created in 2000 for the area shown in Fig. 1. It is based on the developed and tested methods and models (Kochergin *et al.* 1999a, 1999b, 2000b) and communication channels with real-time data. The first version of this system is set up on FERHRI server and is on free Internet access. Paper dwells on the peculiarities of on-line modeling technique, description of the applied initial information, models, methods and results of modeling testing.

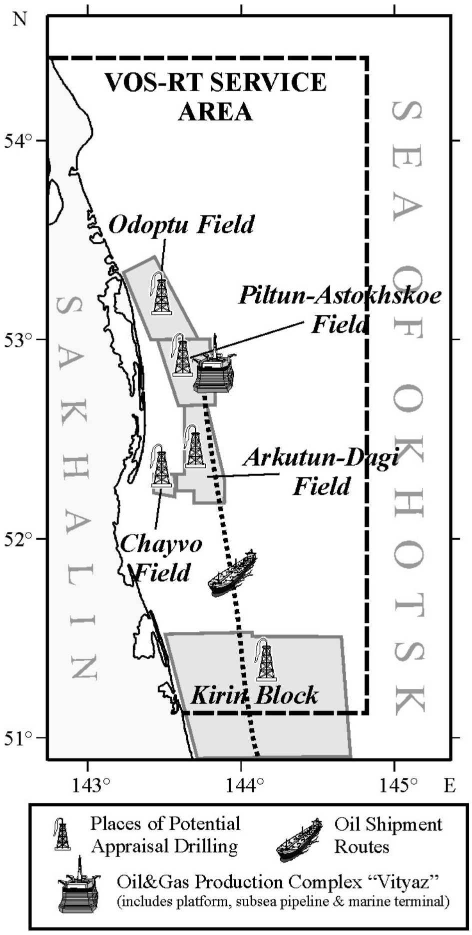

Fig. 1. Service area of on-line oil-spill modeling system with potential oil-spill objects on the Northeastern Sakhalin shelf

On-line Technique Description

The first version of the on-line modeling technique for the oil spills, VOS-RT 1.0, is set up on FERHRI’s server with free Internet access. At present time two interfaces for working with the system are available: e-mail based and web-input-email-output modes. This technique incorporates hydrometeorological data and models that allow to predict the possible fate of the oil spill during July-November and ensures receiving forecasting results that cover up to 68 hours from the input of information in real time. Oil&gas production complex “Vityaz” is considered to be the centre of service area as this is the most potentially dangerous production object in the region. It is also taken into account that the oil spill during the forecasting modeling not exceed the bounds of the area under calculation, *i.e.* 142°40'-144°50'E and 51°10'-54°30'N (Fig. 1). General scheme of the operative forecasting technique is given in Fig. 2.

On-line modeling system consists of a computer server (see Fig. 2b, FERHRI Server in Dep. of EOED) having a number of programs for processing initial information, hydrometeorological models and oil spill fate models and for interpreting those results. It has its own Internet channel and a channel to connect with the specialized hydrometeorological database of the World Meteorological Organization (WMO).

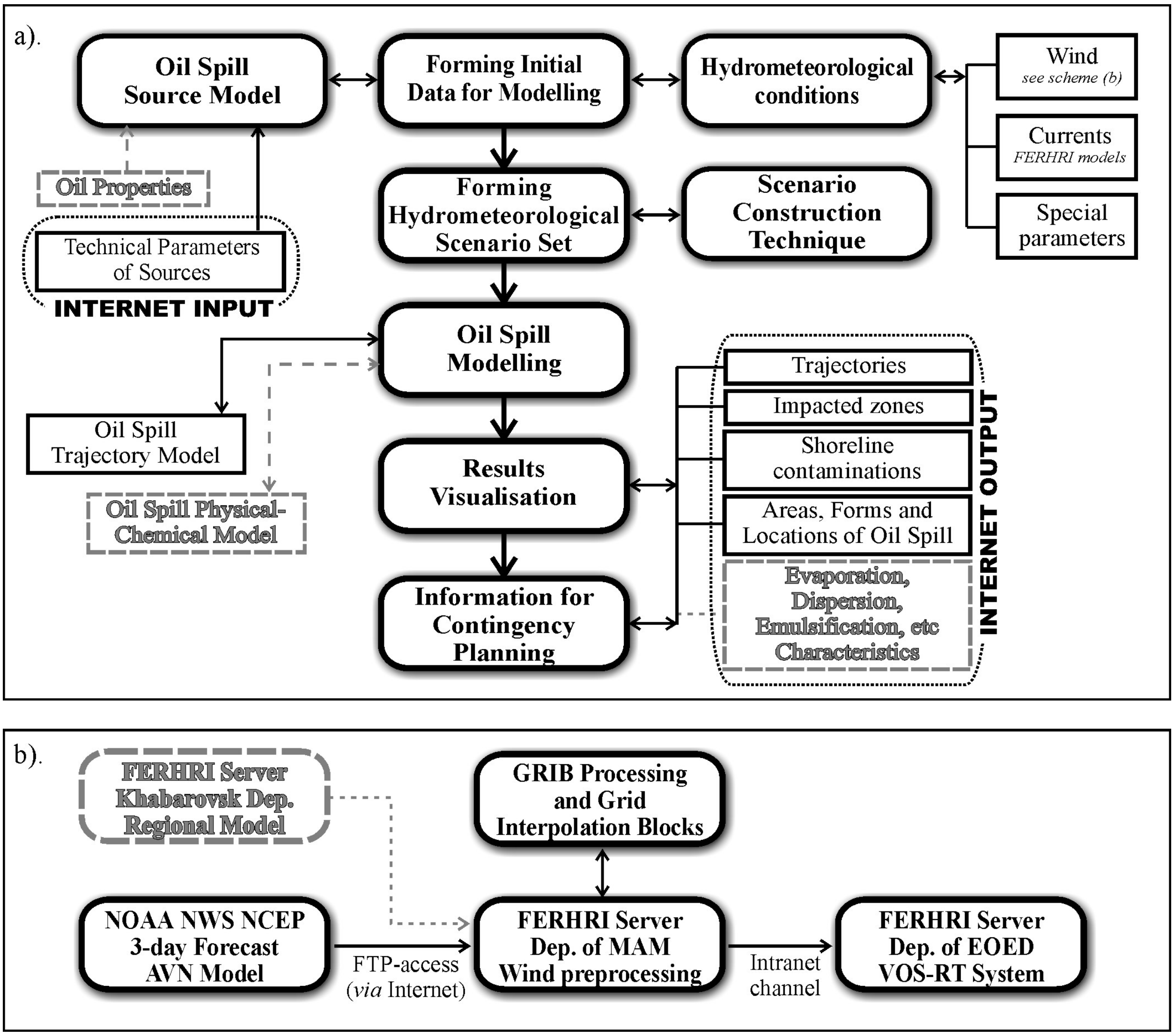

Fig. 2. General scheme of on-line oil-spill modeling technique (a) and wind forecast block scheme (b) (Notes: gray-dotted blocks are not implemented yet; MAM – Dep. of Mathematical Automation of Measurements; EOED – Dep. of Department of Engineering Oceanology and Ecological Designing)

On-line modeling software includes:

- a number of electronic maps of the region with the objects of oil and gas production being marked;
- system of meteorological data input and preliminary processing used for construction of the prognostic surface wind fields (up to three days) for the surveyed area;
- model for constructing tidal current fields of any duration;
- hydrodynamic model for constructing currents under the determined typical hydrometeorological conditions;

- technique for automatic selection of the typical situations and construction of the corresponding current fields;
- model for constructing movement trajectories, areal characteristics, shoreline impact parameters, and other prognostic characteristics of the oil spill within the modeling time on the basis of the “Random walk” method;
- program for making reports on the modeling results (in Microsoft Office format);
- e-mail user interface for the model handling (oilspillrobot@hydromet.com); modeling results will be sent to user by e-mail in response to letter with initial information. If there is a “Help” notion in initial letter, user will also get directions on how to use e-mail model interface;
- friendly user interface for the model handling (available on FERHRI website http://www.hydromet.com); it is used for the on-line modeling task entry as it gives the user step-by-step directions and checks correctness of the input information.

Methods, Models and Initial Data

Hydrometeorological data used in on-line modeling includes the wind and current fields and temperature.

Wind

Wind forecasts are made with the help of global AVN model developed by National Center for Environmental Prediction (NCEP of National Weather Service, NOAA, USA). It is available via Internet channels (Fig. 2b). The forecast term is 72 hours, step of grid is 1.25° and temporal discreteness is 6 hours. Then forecast (in GRIB format) is interpolated for the surveyed area into 10' grid nodes with one hour discreteness. Forecast results are then improved in accordance with actual wind observations obtained by three coastal hydrometeorological stations and Molikpaq (complex “Vityaz”) meteorological station (Fig. 3). At present time FERHRI’s department in Khabarovsk is testing the regional hydrodynamic model (Verbitskaya & Myakina, 2000) developed by Losev V.M., Roshydromet (Fig. 2b) that is based on more precise regional objective analysis and takes into account regional peculiarities.

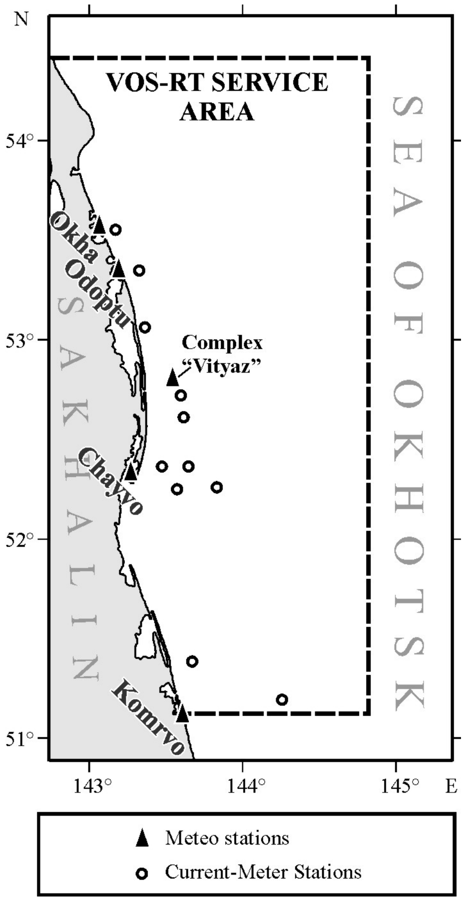

Fig. 3. Location of the current-meter, coastal and marine meteorological stations

Tidal Currents

Northeastern Sakhalin shelf is characterized by the strong diurnal tidal currents; their characteristics are described in (Kochergin *et al.*, 1999c). 12 instrumental current series for 1986-2000 period measured for the northeastern Sakhalin shelf area were used as initial information for construction of prognostic tidal current fields (Fig. 3). All the time series used exceeded a month and were calibrated for mistakes and failures.

Then basing on the least-squares method calculation was made of the harmonic constants of the main diurnal K_1, O_1, Q_1 and semidiurnal M_2, S_2 parameters of the tidal waves. P_1 diurnal harmonic constants were determined by additional corrections of amplitude ratios and phase shifts. Zonal and meridional components were corrected in the same way.

Tidal wave vectors were changed from polar co-ordinates (amplitude, phase) to Cartesian. Projection values obtained were then inter- and extrapolated within the bounds of the surveyed area into 10' grid nodes taking into account shallow water equations for the amplitude and phase of waves.

Residual and Wind Currents

Deep water oceanographic observations for the period of 1947-1995, as well as typical wind situations for the summer and autumn seasons are taken as input information for calculating current fields in the northeastern Sakhalin region bounded with 48°-54°30'N, coastline and 146°E.

Numerical experiments are carried out within the diagnostic model of an Ekhman type (Sarkisyan, 1977; Budaeva & Makarov, 1999) that is based on motion equations in the Cartesian coordinates. It has traditional approximations and ignores the horizontal turbulent exchange. Equation system is approximated using the orthogonal grid with horizontal 10×10 minutes resolution. Vertically the grid is uneven, velocity components are calculated for 18 levels. Shoreline location and sea depth at the grid nodes are taken from the bathymetric map of the northeastern Sakhalin coast. Values of flow function for indistinct boundaries of the surveyed area are determined basing on the quasi-geostrophic approach (Sarkisyan, 1977). Calculation of boundary conditions was made for each season using information on temperature and salinity. Then corrections of flows were made over all boundaries to meat balance proportions.

Hydrometeorological Scenario

Prognostic hydrometeorological scenario confines to the construction of the dependent wind, tidal and nontidal current fields. Scenario construction technique for statistical purposes is described by Kochergin *et al.* (2000a).

Surface nontidal current field directly depends on the near-water wind and density structure of waters determined by seasonal and inter-annual variations due to the actual synoptic conditions. Long-term winds are also considered (Kochergin *et al.*, 1999c). It is supposed that short-term influence of wind on the sea surface is not able to form a stable current scheme. The predicted wind field is used to construct scenarios for the typical wind situations and to optimize these results under various tolerance criteria. In order to define typical wind fields the corresponding current fields are first constructed taking into account smoothing of transitions and the time lag of current field formation. The said technique was tested using the synchronized series of wind and current calculations for the surveyed area.

Construction of the tidal current field does not depend on wind parameters and finally it is synchronously added to the nontidal current fields.

Oil Spill Fate Model

The on-line system described herein uses a simpler model for predicting oil spill fate than the previous researches made for statistical purposes (Kochergin *et al.*, 2000b). That is why the system of operative forecasts is based on the trajectory model together with the estimations of the chemical processes occurring in the oil slick that were made for the typical oil and average Sakhalin conditions. Trajectory model describes oil spill drift under the given hydrometeorological situations and currents, it includes the methods of oil spill square calculation and its interaction with shoreline.

Trajectory model represents an oil spill as a number of oil slicks, each spreading independently. An oil slick consists of a finite number of markers representing the shape and oil distribution within a slick. The below equations (preliminary introduced by Kochergin *et al.*, 2000b) describe the trajectories of markers conditioned by the determinate (currents, wind, spreading mechanisms) and stochastic (turbulent pulsation) processes:

$$\frac{dx_i}{dt} = u(x_i, y_i, t) + u'(x_i, y_i, t) + kw_u(x_i, y_i, t) + f_u(x_i, y_i, t),$$

$$\frac{dy_i}{dt} = v(x_i, y_i, t) + v'(x_i, y_i, t) + kw_v(x_i, y_i, t) + f_v(x_i, y_i, t),$$

where, x_i, y_i - coordinates of i marker;

u, v - liquid velocity components (currents);

u', v' - components of turbulent pulsation rate;

w_u, w_v - zonal and meridional components of near-water wind;

k - wind drift coefficient ranging from 0.025 to 0.035 and depending on the wind effect upon surface currents;

f_u, f_v - rate components of oil spill spreading.

Thus, the motion of markers in Equations accounts 4 mechanisms of oil spill spreading. Rate component f contains the first three spreading phases, inertia, gravitation, and surface tension, described in accordance with (Fay, 1971). The fourth diffusion phase is described by u', v' rates of turbulent pulsations using the "Monte-Carlo" method and spatial-temporal scales of turbulence, according to (Ozmidov, 1986).

Initial conditions set up the coordinates of oil spill markers according to time and location of an accident. Each series of markers released by a source has the "main" marker. Migration equation contains no stochastic members for the "main" marker. An oil spill, according to mechanisms of (Fay, 1971; Ozmidov, 1986), spreads around this "main" marker. The square covered by an oil spill is numerically calculated. Calculation accounts distribution of the field of markers, with the required film thickness of 0.1 μm, not less, being critically observed.

The chemical processes of quick evaporation and emulsification have the dominating influence on the oil spill fate. For example, about 60% of light oil carbohydrates are evaporated during the first two hours after the spill (Michoukov *et al.*, 1997). This is also considered when calculating the spill square. A more detailed description of the model for physical and chemical oil evolution is cited in (Kochergin *et al.*, 1999a).

The model of the oil spill source is constructed with the help of the set up spatial position, geometric characteristics, detailed regime of oil input.

Testing of the Technique

During the process of verification of individual models and calculation methods (such as construction of current schemes) on-line modeling technique was tested element by element. Complex verification of the modeling technique over comparison of calculated and actual spill characteristics in 1989 (Michoukov & Abramova, 1997) and 1999 (Kochergin *et al.*, 2000b) was also carried out.

Wind. Testing of the predicted surface wind fields in the service area confined to their comparison with the real observations made by three coastal (Okha, Chaivo and Komrvo) and a marine hydrometeorological stations (production complex "Vityaz") (Fig. 3). Testing was made in autumn 2000 for two calculation techniques. The first – AVN model developed by NCEP – ensures maximum forecast term of up to 72 hours and is currently used in the on-line system. The second one – FERHRI regional model (Verbitskaya & Myakina, 2000) – provides 48-hours forecast and is applied in the WMO regional forecasting center in Khabarovsk. Quality criteria show that both models produce quite adequate wind forecasts which can be used for the operative purposes.

Currents. Testing of the constructed tidal current schemes was carried out over the retrospective series that resulted in a high correlation between prognostic and actual series (up to 0.9) (Kochergin *et al.*, 1999c). Less accurate results were obtained for the boundaries of the surveyed area. As for reversibility and other tidal current characteristics it should be mentioned that they can influence the oil spill transport within 100 km from a source. Thus, the engineering approach used is successfully applied here and it gives accurate predictions of the tidal currents near the potential pollution source. This is especially important for the qualitative forecasting during the first two days.

Sustaining statistic dependencies in the total current fields at the sites covered by instrumental observations was the main method used for the total current model verification. The ensemble of nontidal current fields was represented as a set of typical "summer" or "autumn" situations for the period of 2400 hours accounting to statistic characteristics of the corresponding wind fields. The constructed nontidal current series were added to the calculated tidal currents. For the total data series the probability characteristics of surface velocity and direction were constructed as well. Analogous probability characteristics were determined over the instrumental data series during the two periods, "summer" – before September 15, and "autumn" – after September 15, and united into test data series. Comparative analysis revealed good correlation, especially for autumn characterized by more stable currents, *e.g.* see (Kochergin *et al.*, 2000a).

Trajectory and Fate Models. Trajectory model was tested on the observed data of local spills. Comparison of the calculated and observed trajectories of the oil spill occurred in autumn 1999 is shown in Fig. 4. The observed trajectory was constructed using the ship-and-helicopter data. The calculated trajectory is based on the wind data series with 6-hour discretion typified into three types (Fig. 4d). Nontidal current fields were calculated for typical wind situations and tidal currents were calculated over the period of spill observation (Fig. 4d). Local time shown on trajectories indicates the spill at the moments it was observed from ships and a helicopter. Comparison revealed good precision of model calculations using real wind data and modeling hydrological information.

Accuracy of the physical-chemical model of oil spill fate was confirmed by the real data observed during the *in situ* field experiment with the oil spilt on the Sakhalin shelf (Michoukov & Abramova, 1997).

Conclusion

The described results demonstrate possibilities of on-line modeling technique for the oil spill forecasting in ice-free period on the northeastern Sakhalin shelf area for the time period of up to 68 hours. The on-line calculated characteristics of the oil spill trajectory, spreading, and interaction with shoreline can be used in the real time contingency planning in case of accident. At present time the first version of on-line system is available on Internet request and may be used freely by the departments of the Russian Emergency Ministry and companies that are exploring the Sakhalin shelf. The system consists of several blocks including hydrometeorological blocks of wind and current forecasting and the modeling block for the oil spill fate. Further improvement of the described technique includes development of a more qualitative system blocks for forecasting oil spill fate in real time and arrangement of additional verification experiments.

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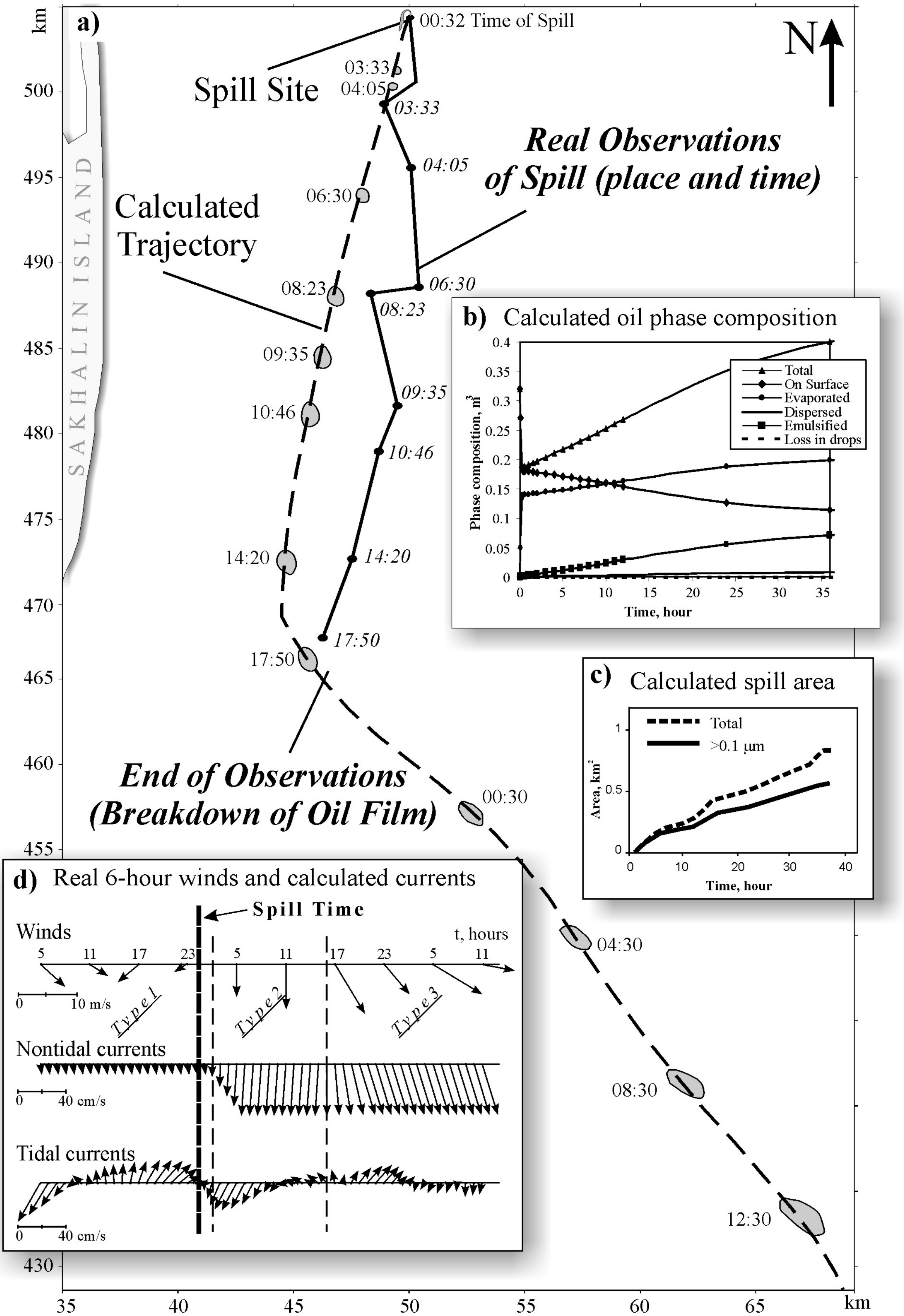

Fig. 4. Calculated and observed trajectories of the real oil spill accident on the northeastern Sakhalin shelf (a); calculated phase composition (b) and spill area (c) characteristics by time; (d) – real wind vectors and calculated nontidal and tidal current vectors used in modeling

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