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Direct and inverse modelling for environmental risk assessment and emission control

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A concept of environmental modelling and its applications for Siberian regions are presented. The regions are considered both as sources and receptors of pollution as elements of the global climatic system. A methodology has been developed to build the combined methods of forward and inverse modelling for the problems of the air quality, environmental risk assessment and control. It is based on variational principles and methods of adjoint sensitivity theory. This allows obtaining the optimal numerical schemes and universal algorithm of the forward-inverse modelling. Following the concept, the functionals (describing the generalised characteristics of the processes, data, and models) are considered together with the basic model components. To combine all these elements in the frames of forward and inverse relations, we suppose that each of them may contain uncertainty. In this case, it is naturally to formulate a weak-constraint variational principle for the augmented functional which contains the model description in the form of integral identity and the cost functional including the total measure of all uncertainties. The stationary conditions for the augmented functional with respect to the variations its functional arguments define the mutually agreed structure of numerical schemes for forward and adjoint problems, and sensitivity relations. For quantitative risk assessment the following characteristics are useful: (i) values of goal functionals and their variations in a form of sensitivity relations; (ii) risk and sensitivity functions to the variations of the sources. It is convenient to take the risk function multiplied by the source function as a distributed risk measure.

The variational technique provides the backward propagation of information, contained in the target functionals, to parameters and sources of the models through the sensitivity and uncertainty functions. This gives a base for realisation of the feedback algorithms and methods of control theory, which are necessary for formulation of multicriteria optimisation accounting different constraints of ecological, economical, and social essence while solving environmental problems such as air pollution control, placement design for new industrial units, etc.

The problems of the long-term environmental forecasting demand revealing the dynamical active zones and the areas of increased sensitivity to the variations of forcings (model parameters). The proposed methodology of accounting the climatic data into environmental studies is suitable for studying such problems. Analysis of the long-term behaviour of the global climatic system and orthogonal decomposition of the multivariate series of meteorological data with respect to the scales of processes allows identifying the activity centers and using this information for construction of scenarios for assessment of risk/vulnerability for sources/receptors.

Such analysis for Siberian regions showed that Siberia is situated in areas which separate circulation systems of high energy activity. For winter, they are the Pacific and Atlantic energy-active zones, whereas the Arctic and South-Asian zones withstand in Siberia in summer. These facts allow an interpretation of climatic instability inherent in the region. During the autumn-winter season, the instability expresses as sharp alteration of weather cycles. The formation of Altai-Sayan cyclogenesis (which is of the same intensity as the Mediterranean) is observed for the warm seasons in the southern Siberia. In climatology it is referred as a lee-type cyclogenesis. This is the large scale phenomenon in the climatic system of the central part of Eurasia. Such specific hydrodynamic background defines environment quality in Siberia. From the point of view of system analysis, the methods of sensitivity theory, risk assessment and control along with scenario approach offer a tool which allows bringing the results of the global atmospheric and climatic studies onto the regional level. Namely, this level puts the concrete questions on the environment quality and its changes such as a choice of plausible strategy for sources control and mitigation of the man-induced impact on environment. Some environmental problems for Siberian regions are discussed, and a number of forward, adjoint and inverse problems for different risk sites and goal functionals are presented.