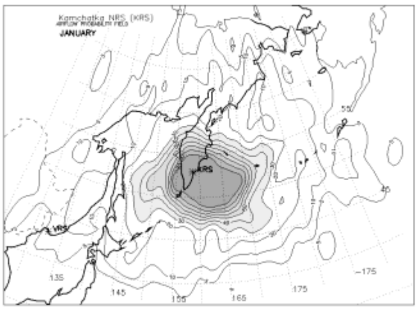
APPENDIX 1

MONTHLY VARIATIONS OF THE AIRFLOW PATTERNS

FOR THE KAMCHATKA NRS



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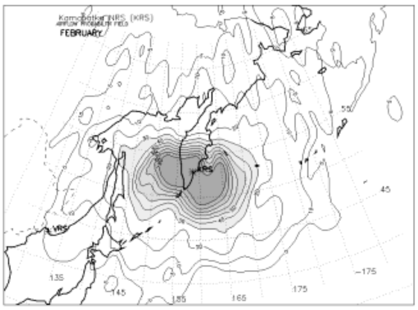

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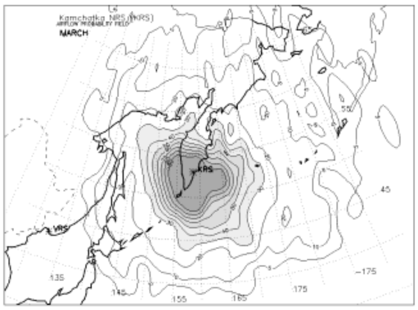

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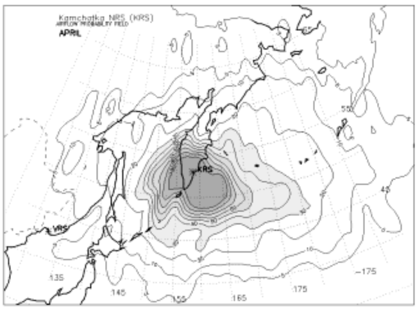

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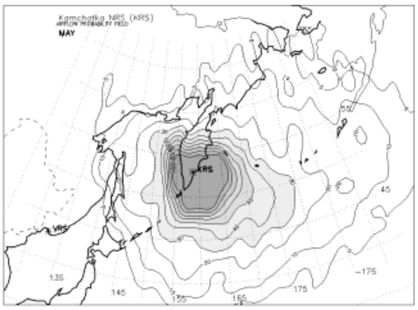

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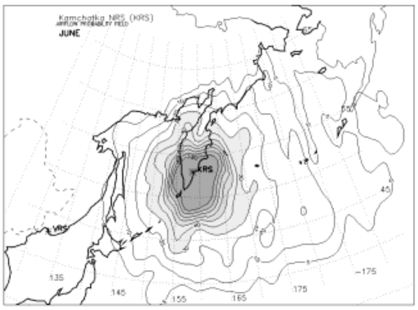

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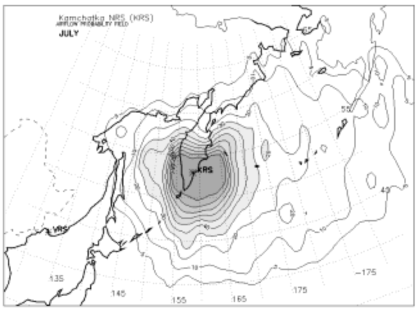

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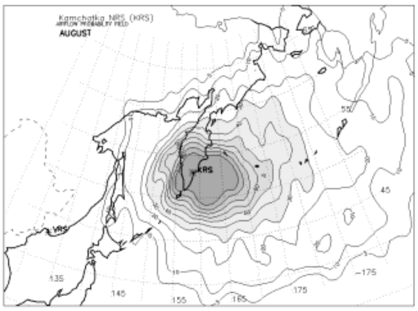

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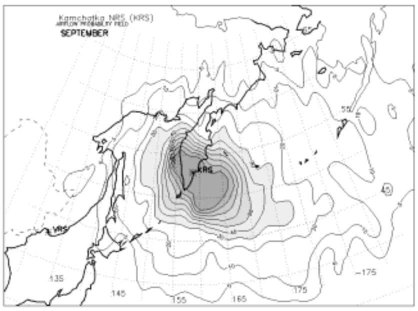

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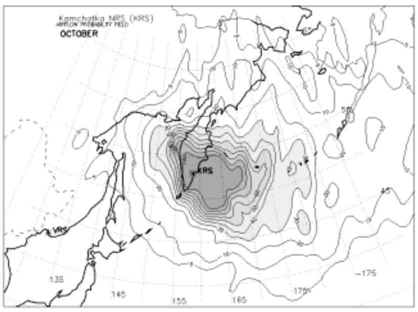

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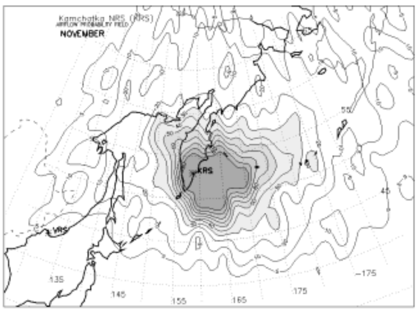

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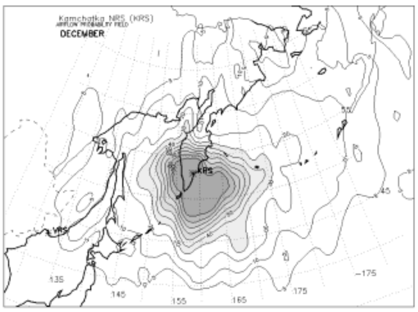
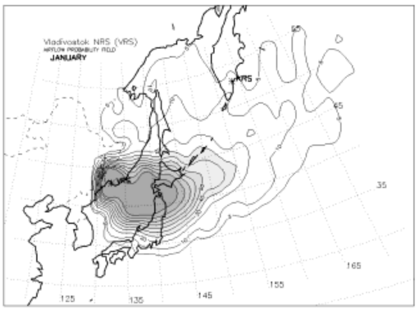


(Dec)

FOR THE VLADIVOSTOK NRS



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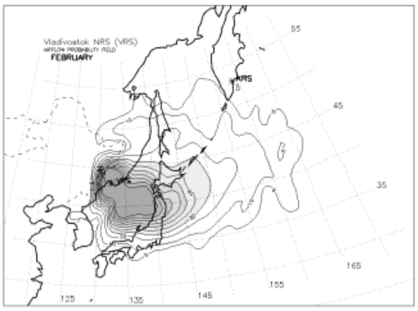

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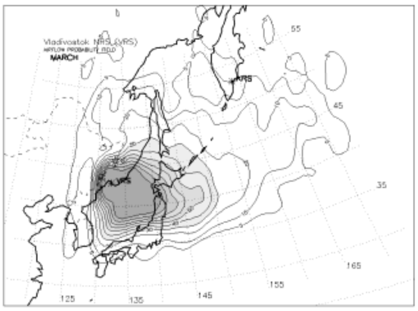

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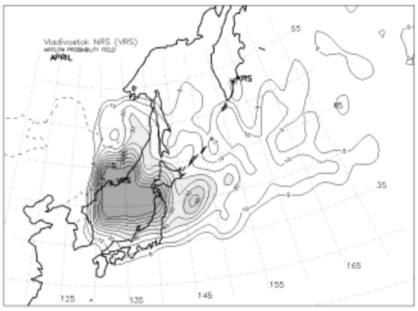

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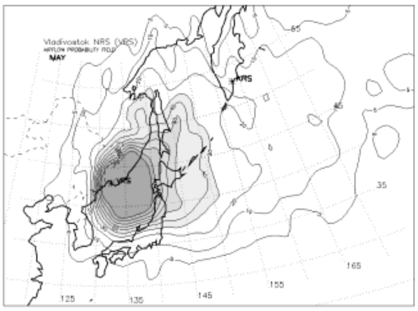

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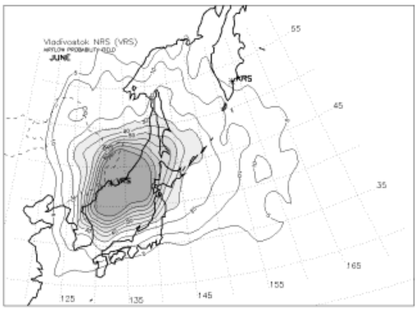

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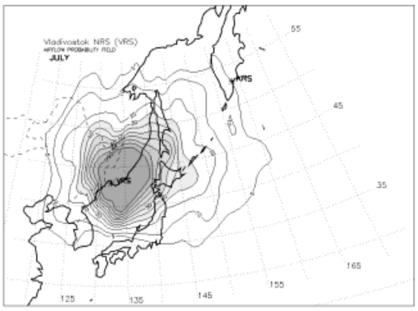

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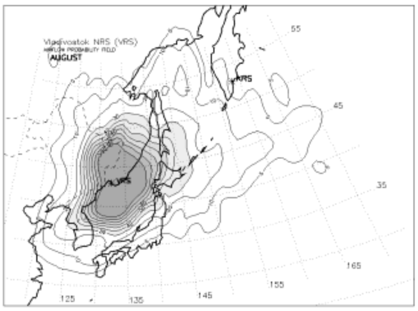

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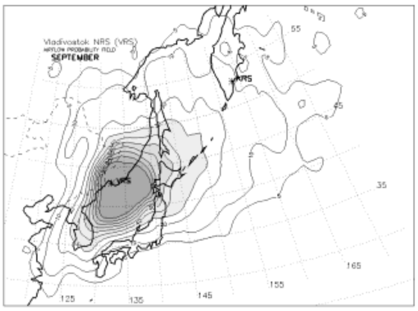

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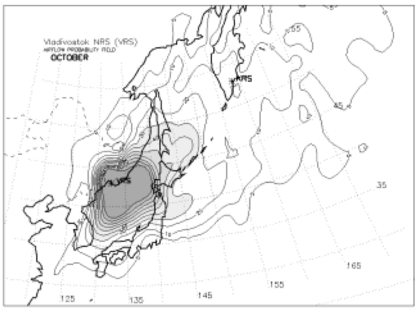

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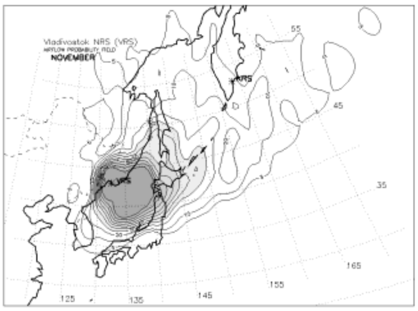

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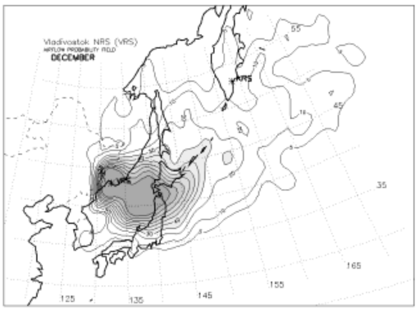
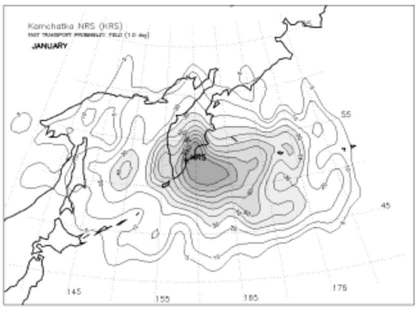


(Dec)

APPENDIX 2

MONTHLY VARIATIONS OF FAST TRANSPORT PATTERNS

FOR THE KAMCHATKA NRS



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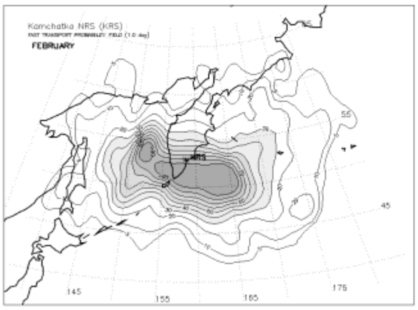

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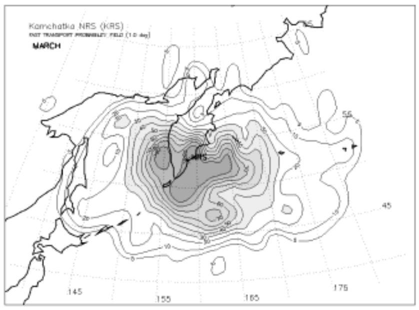

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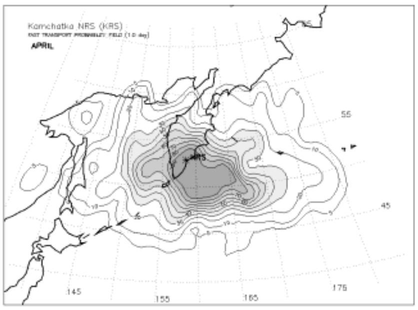

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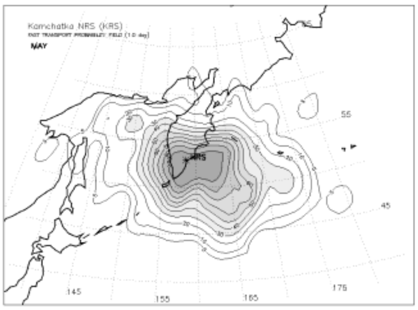

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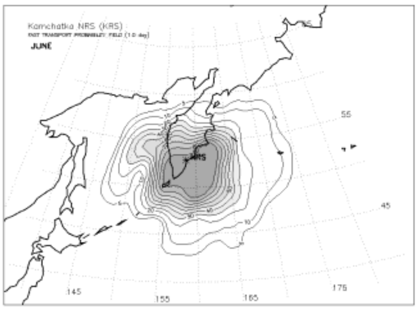

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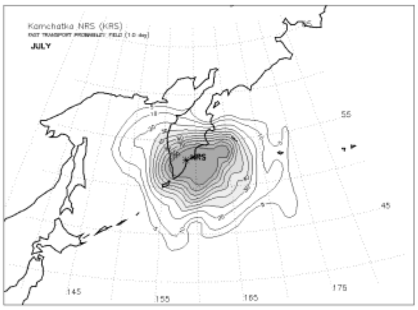

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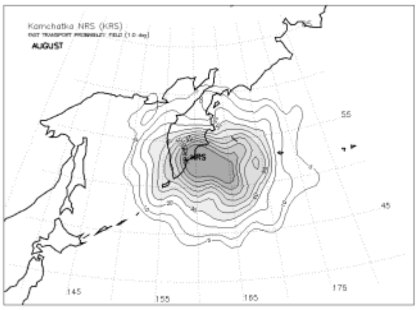

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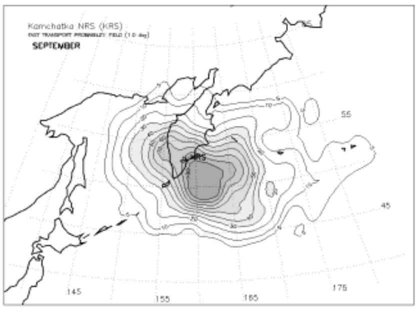

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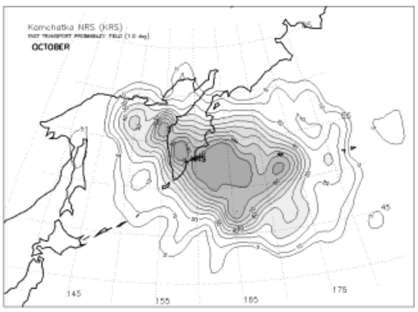

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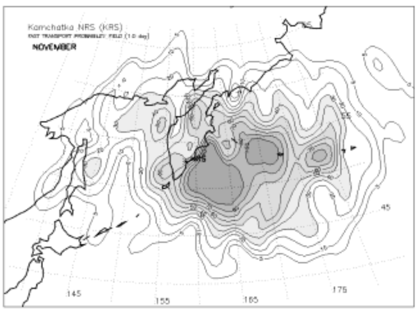

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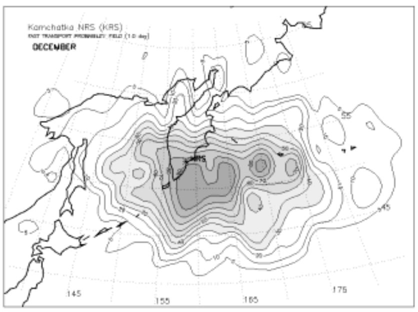
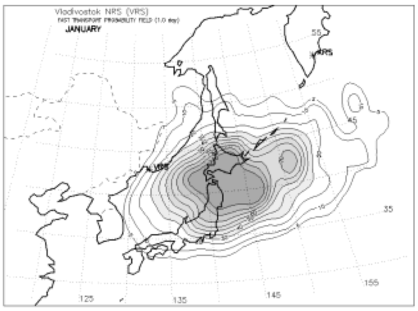


(Dec)

FOR THE VLADIVOSTOK NRS



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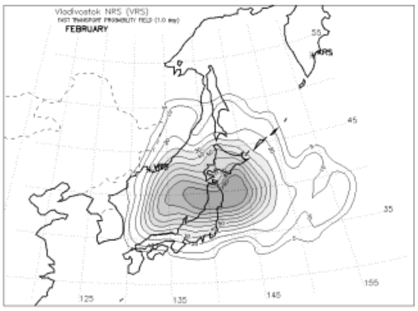

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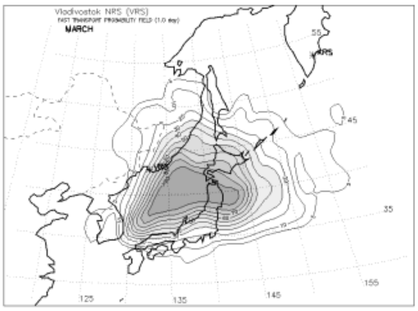

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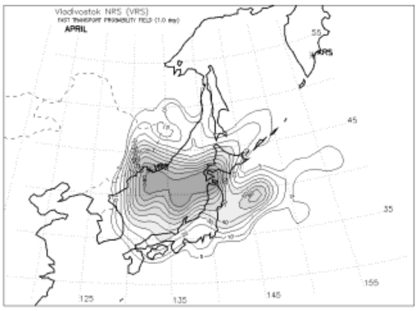

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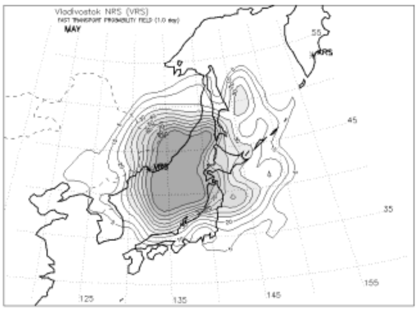

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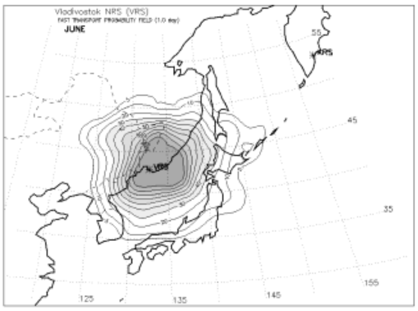

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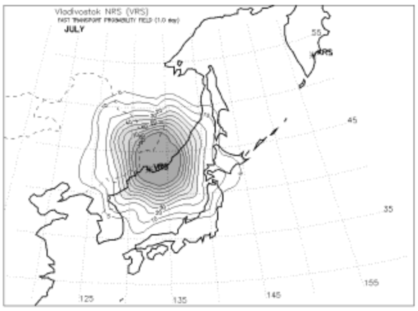

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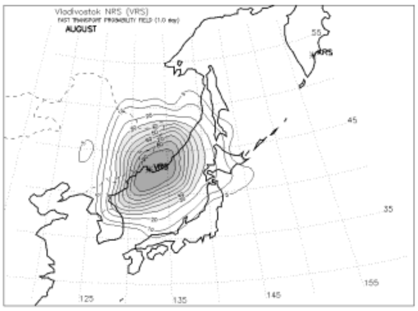

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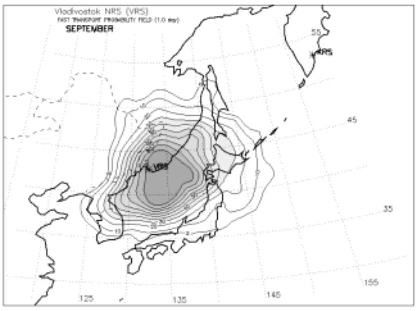

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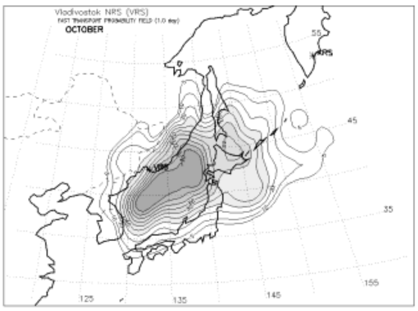

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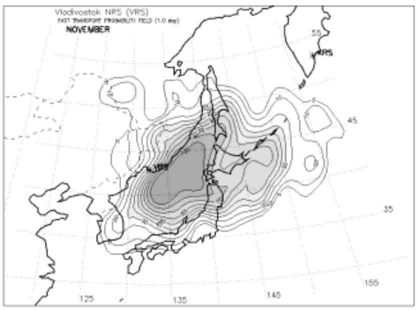

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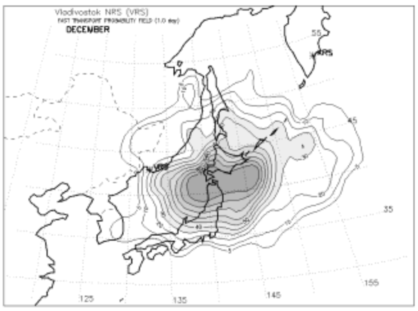


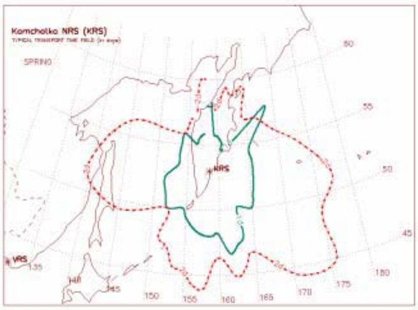
(Dec)

APPENDIX 3

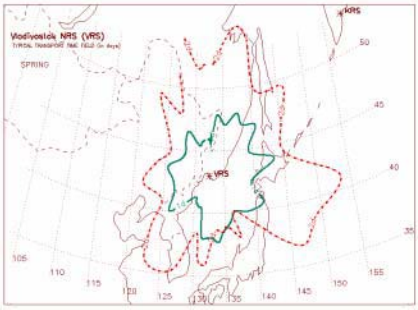
SEASONAL VARIATIONS OF TYPICAL TRANSPORT TIME PATTERNS

FOR THE KAMCHATKA & VLADIVOSTOK NRSs (1 & 2 days)

SPRING

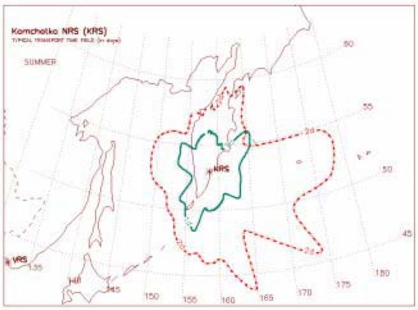


(KNRS)

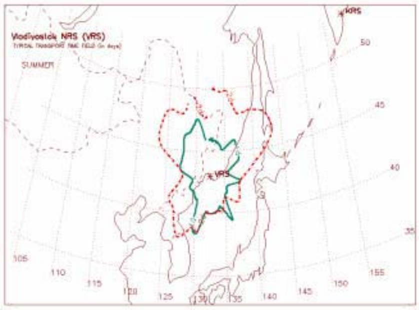


(VNRS)

SUMMER

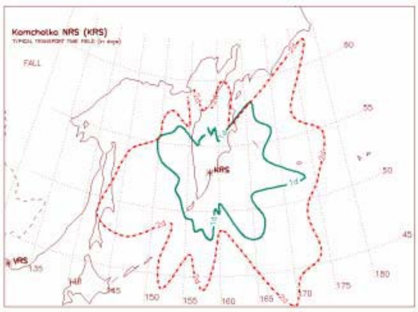


(KNRS)

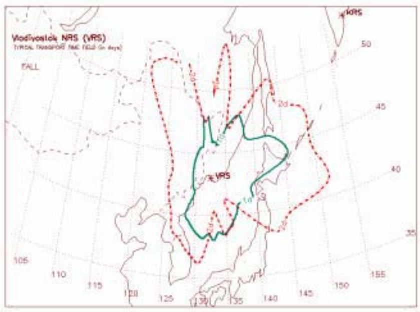


(VNRS)

FALL

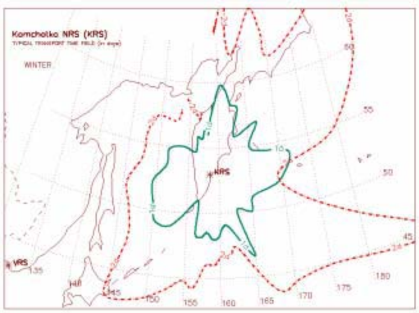


(KNRS)

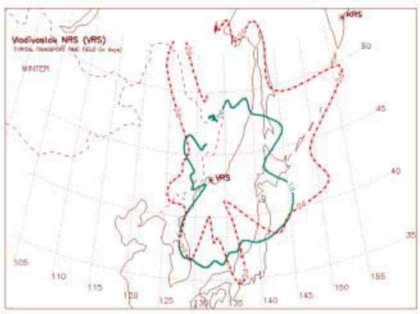


(VNRS)

WINTER



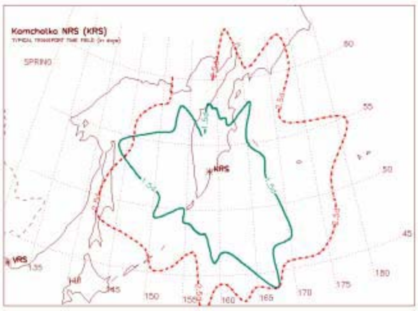
(KNRS)



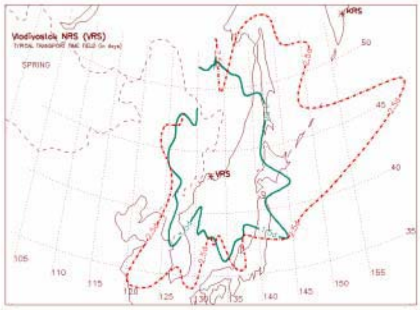
(VNRS)

FOR THE KAMCHATKA & VLADIVOSTOK NRSs (1.5 & 2.5 days)

SPRING

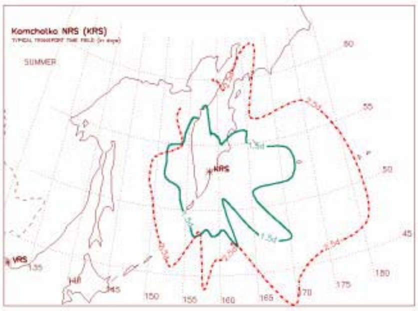


(KNRS)

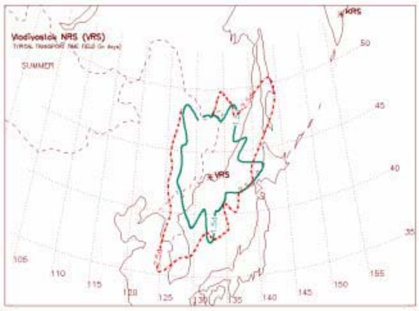


(VNRS)

SUMMER

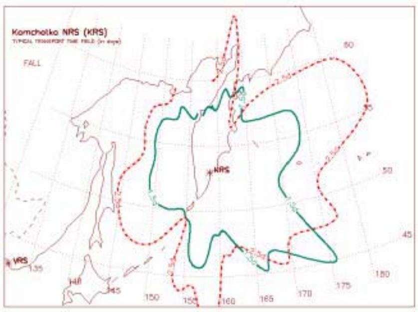


(KNRS)



(VNRS)

FALL



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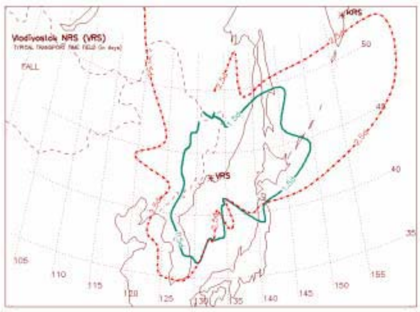
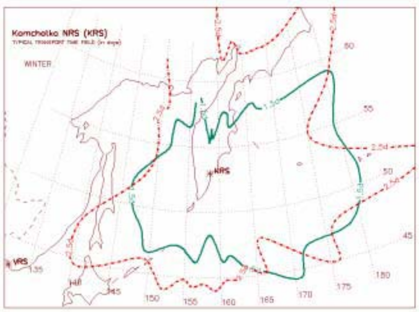
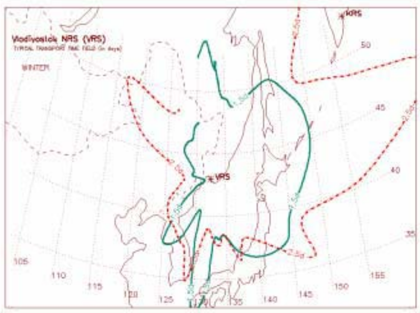


(VNRS)

WINTER



(KNRS)

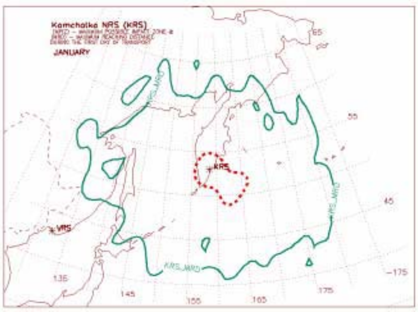


(VNRS)

APPENDIX 4

MONTHLY VARIATIONS OF THE MAXIMUM POSSIBLE IMPACT ZONE AND MAXIMUM REACHING DISTANCE INDICATORS

FOR THE KAMCHATKA NRS



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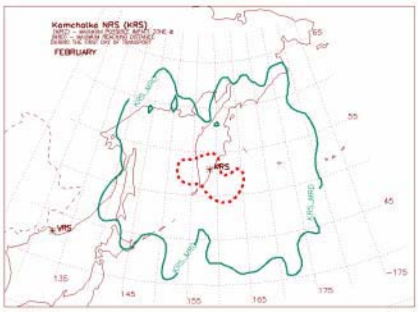

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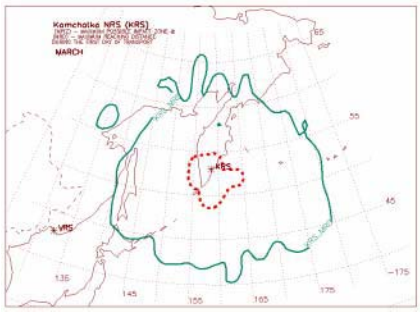

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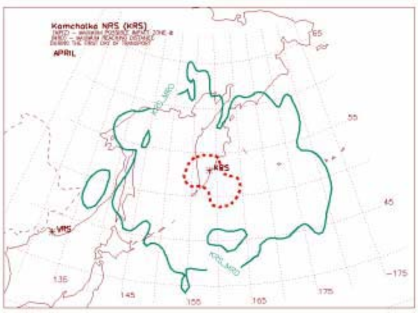

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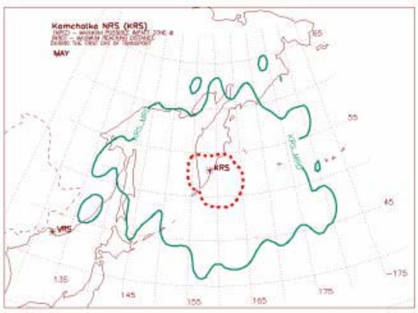

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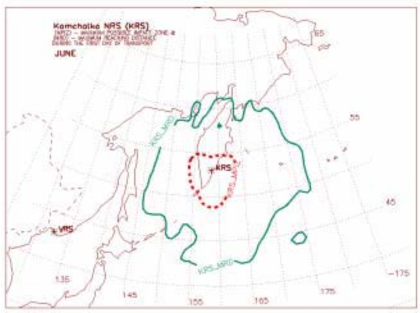

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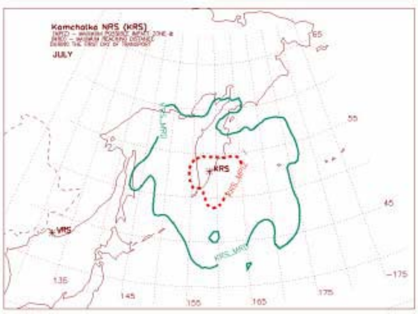

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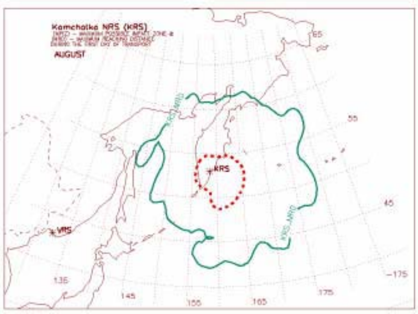

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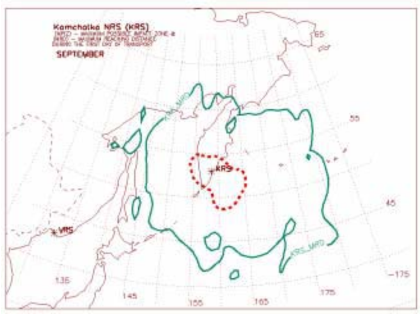

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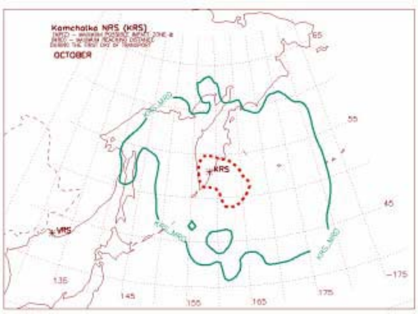

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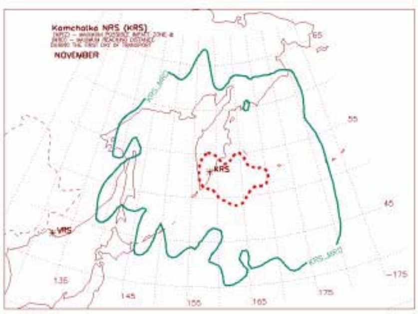

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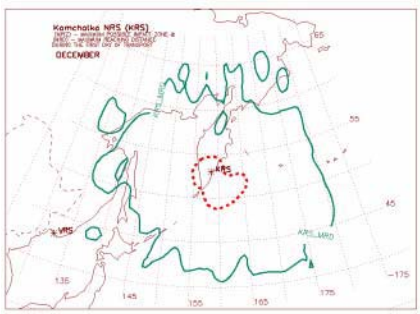

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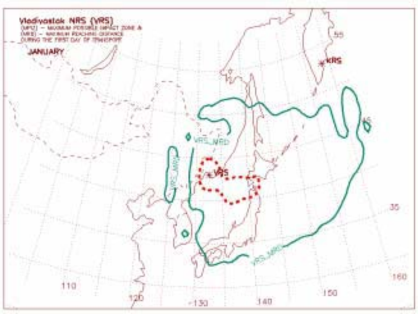
FOR THE VLADIVOSTOK NRS



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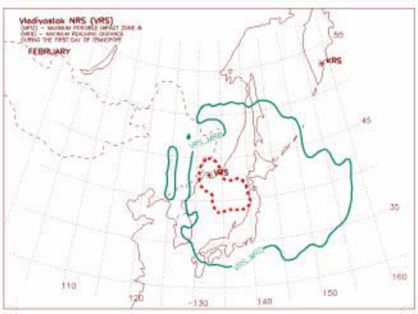

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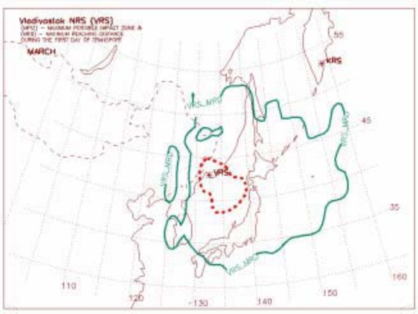

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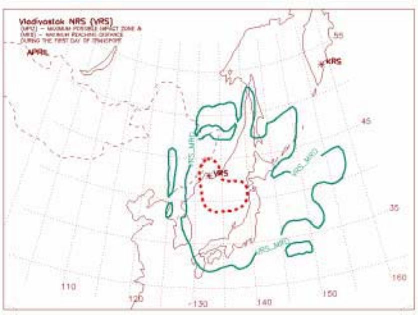

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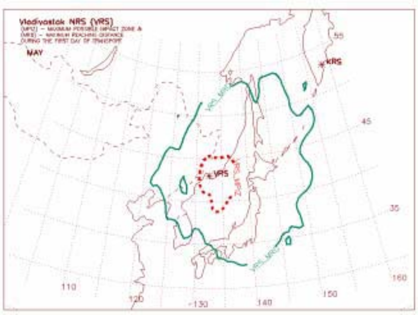

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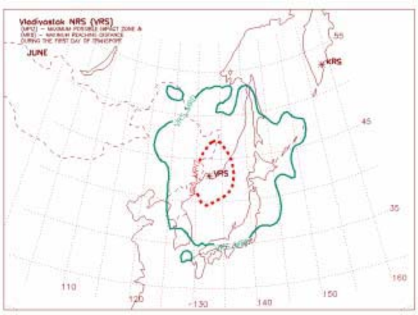

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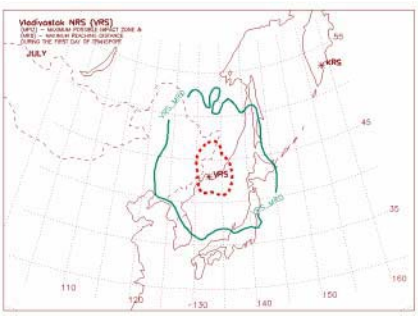

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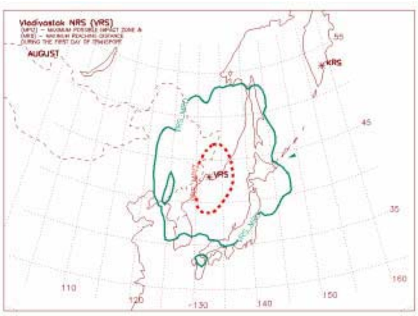

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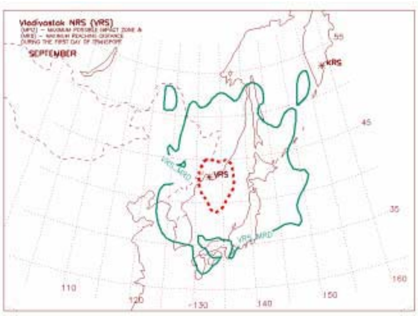

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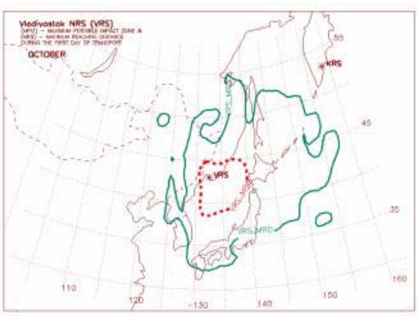

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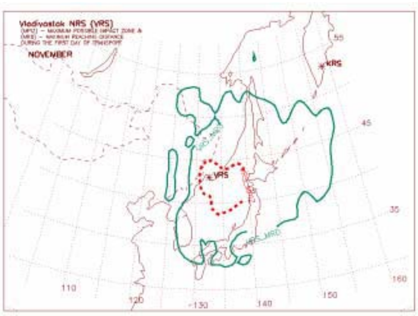

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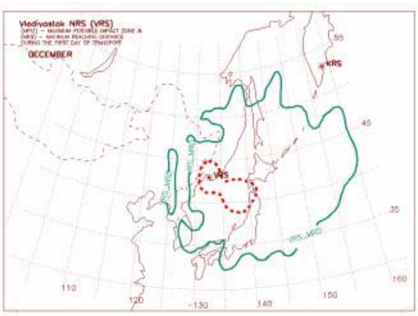

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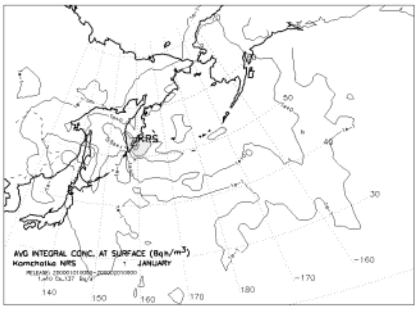
APPENDIX 5

MONTHLY VARIATIONS OF THE AVERAGE INTEGRAL CONCENTRATION PATTERNS

FOR THE KAMCHATKA NRS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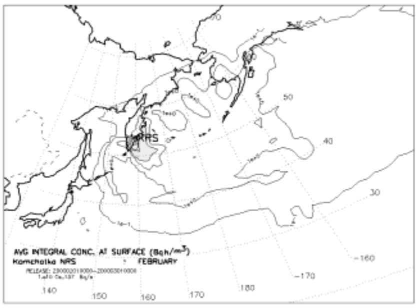
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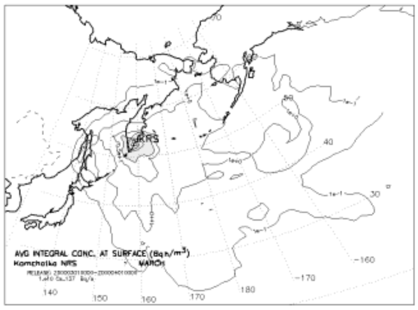
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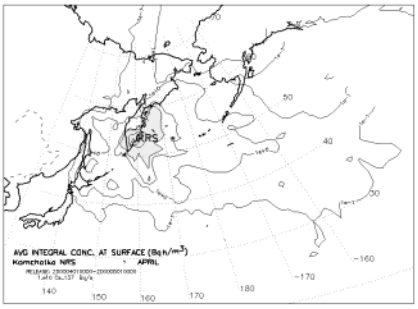
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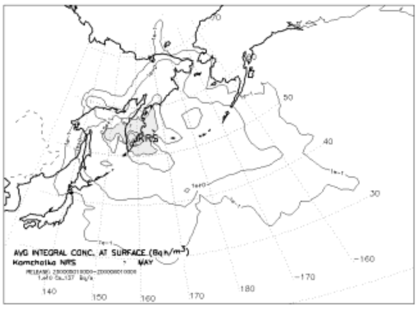
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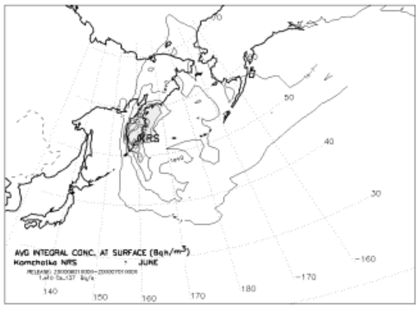
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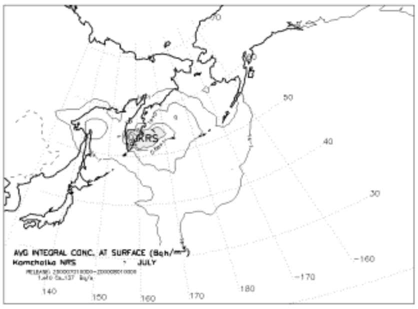
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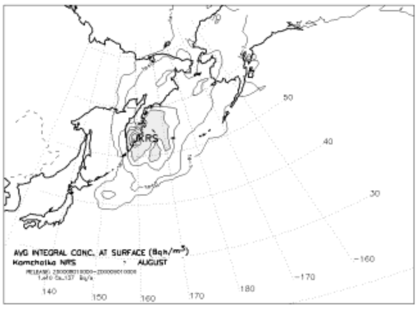
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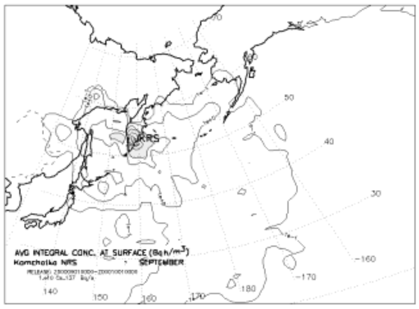
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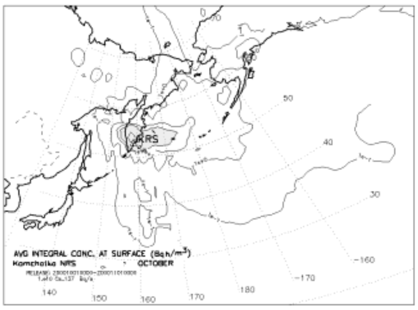
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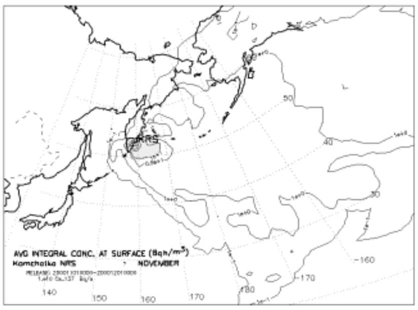
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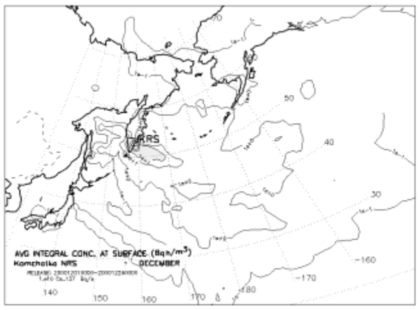
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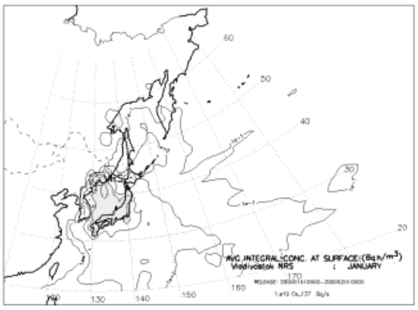
FOR THE VLADIVOSTOK NRS



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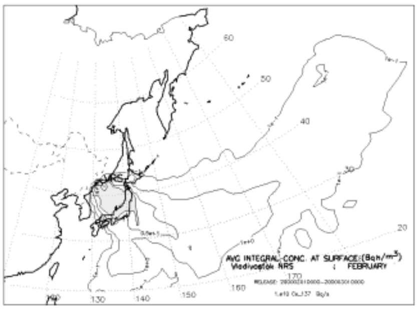

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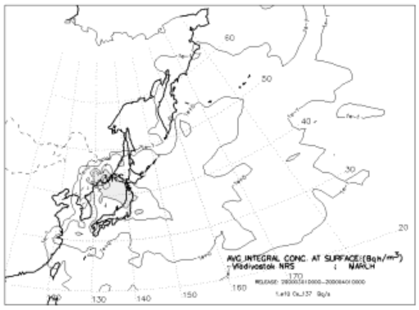

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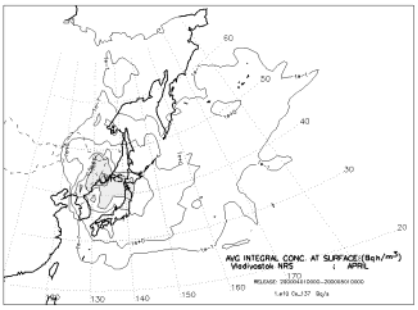

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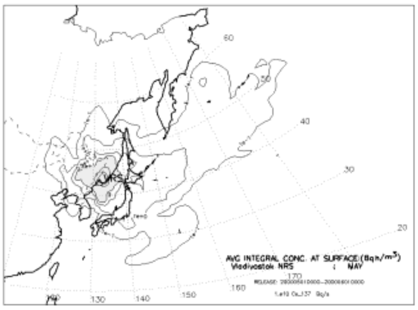

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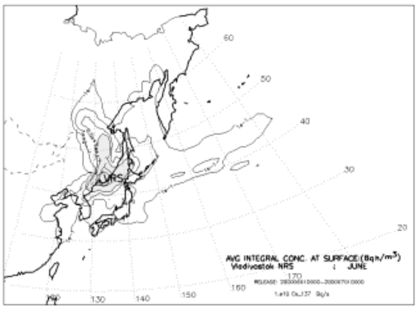

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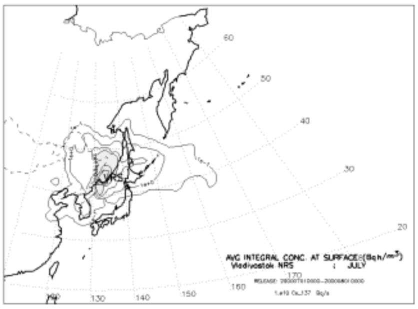

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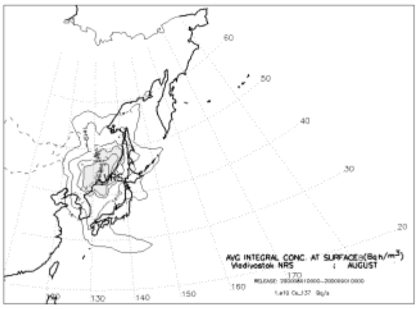

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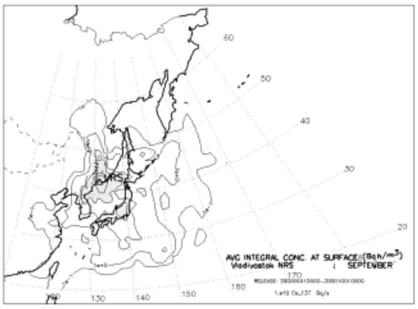

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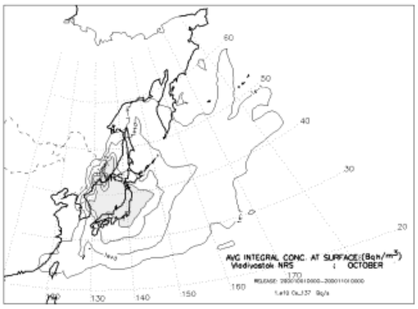

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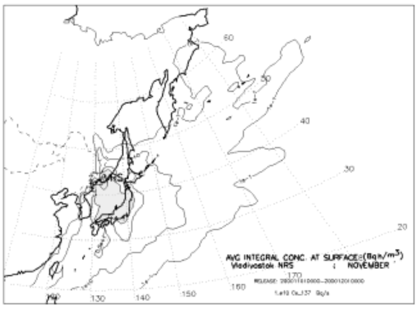

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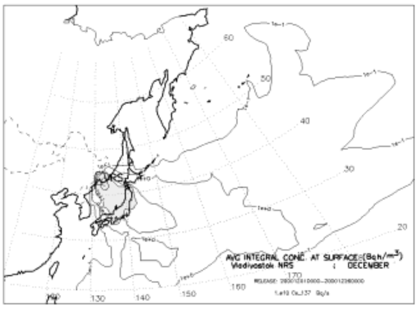

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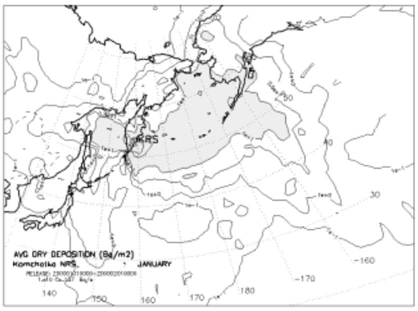
APPENDIX 6

MONTHLY VARIATIONS OF THE AVERAGE DRY DEPOSITION PATTERNS

FOR THE KAMCHATKA NRS



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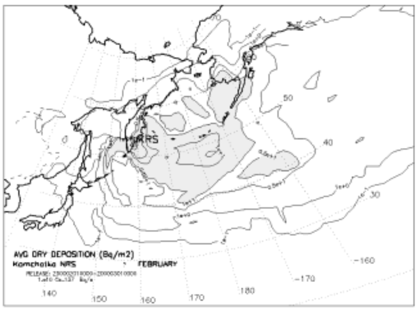

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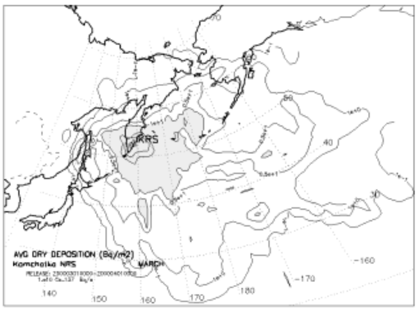

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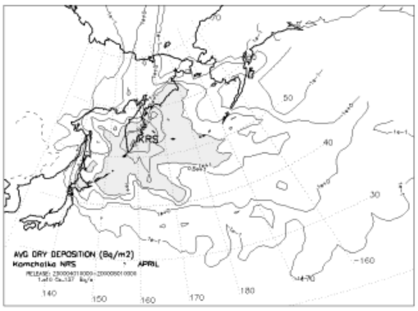

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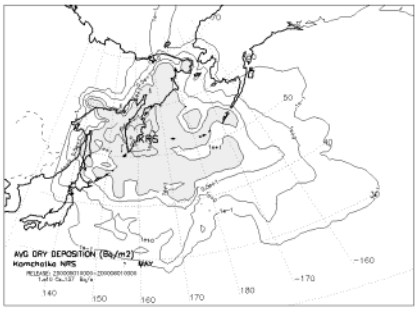

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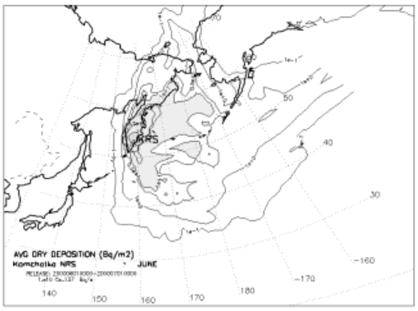

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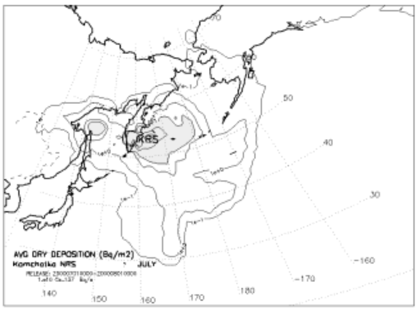

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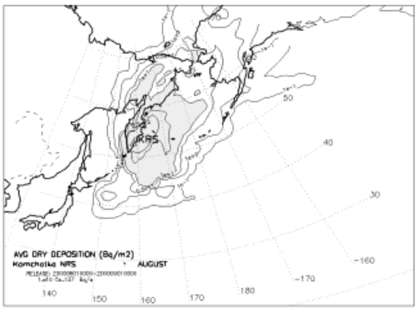

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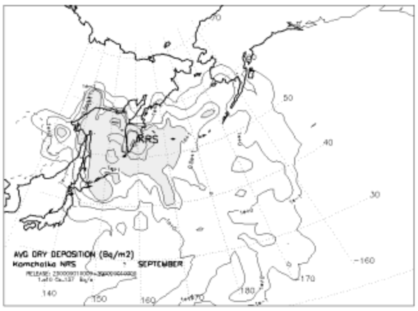

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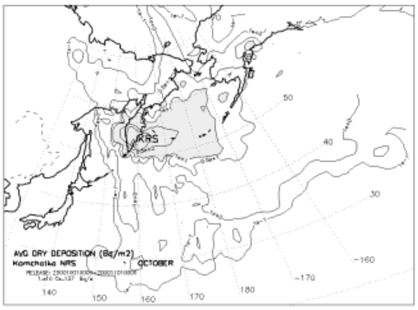

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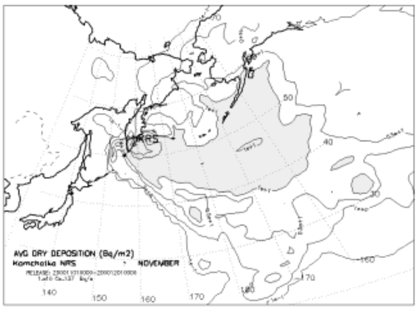

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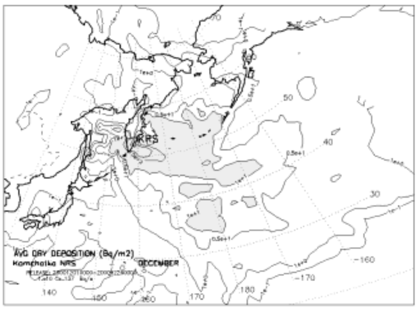

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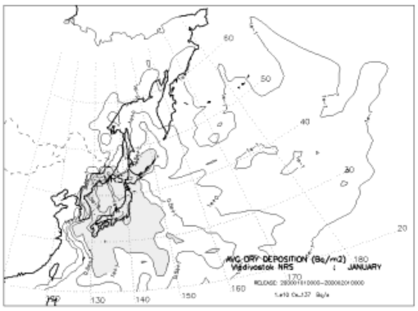
FOR THE VLADIVOSTOK NRS



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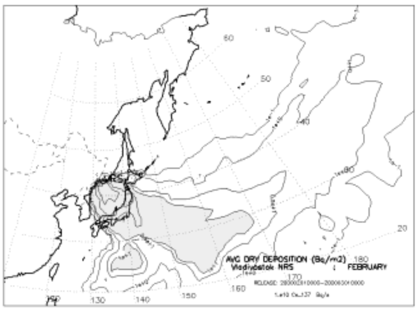

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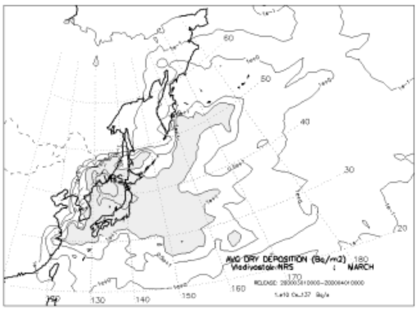

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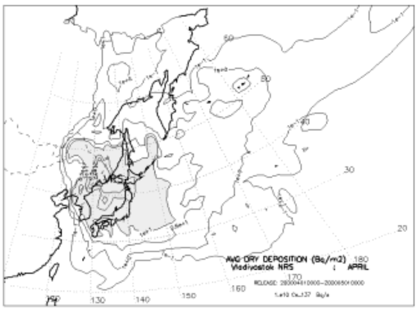

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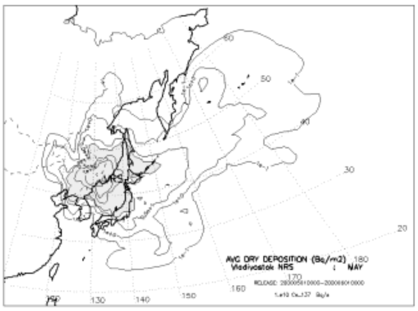

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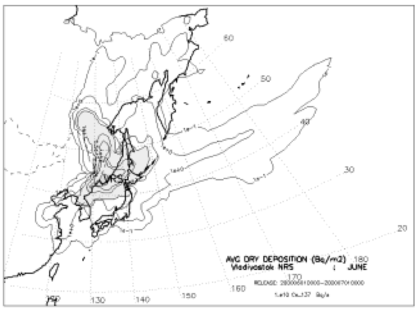

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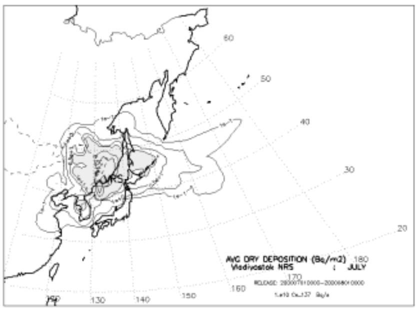

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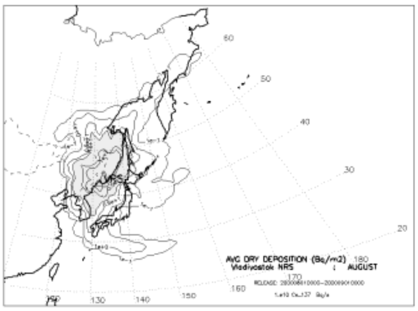

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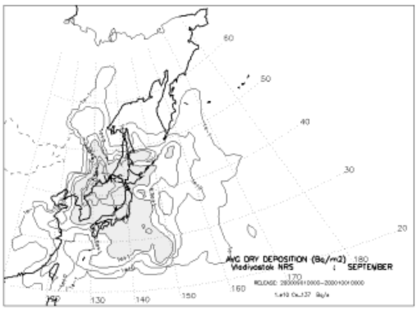

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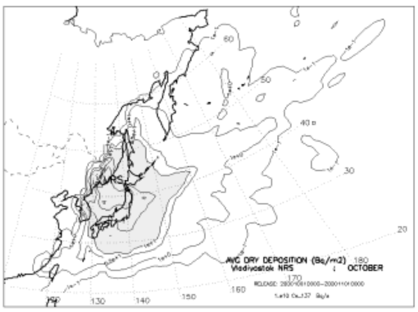

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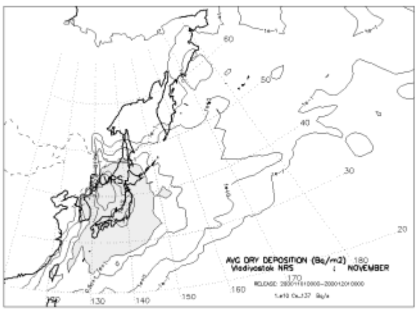

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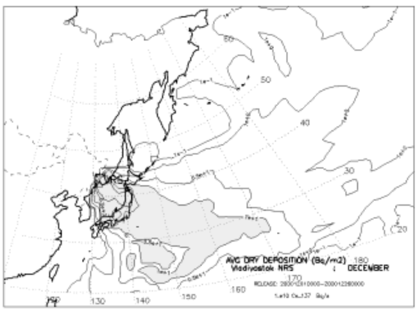

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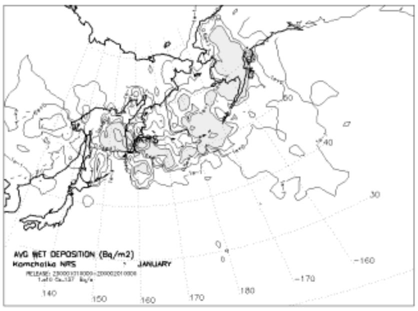
APPENDIX 7

MONTHLY VARIATIONS OF THE AVERAGE WET DEPOSITION PATTERNS

FOR THE KAMCHATKA NRS



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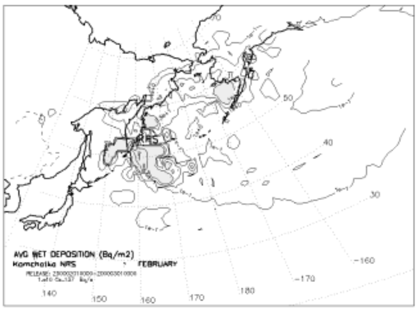

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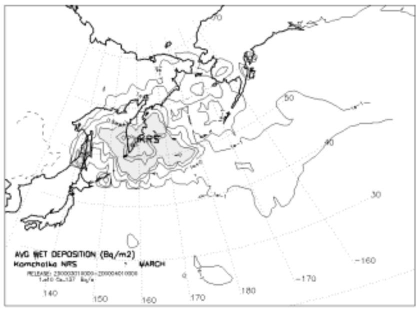

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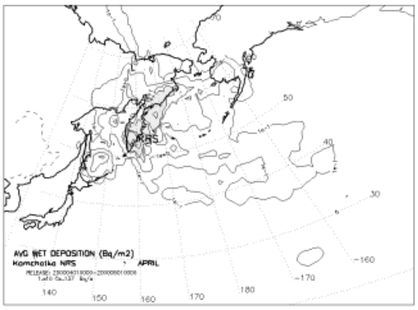

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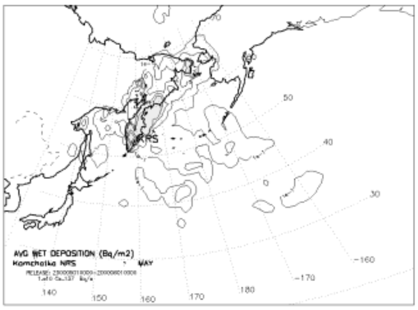

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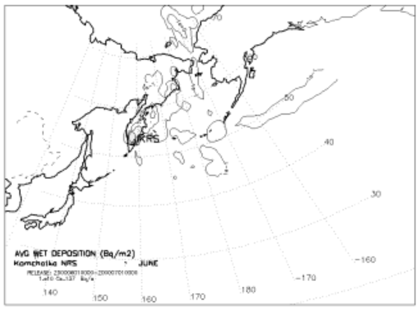

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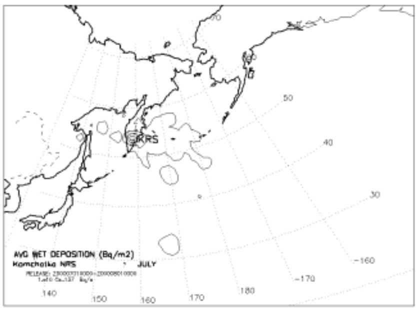

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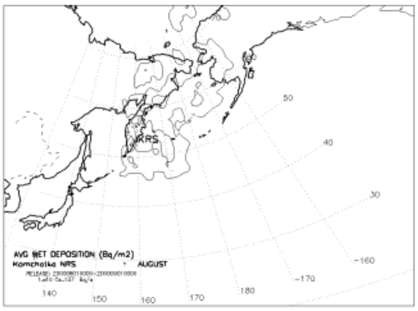

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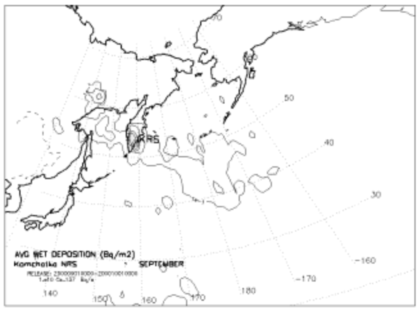

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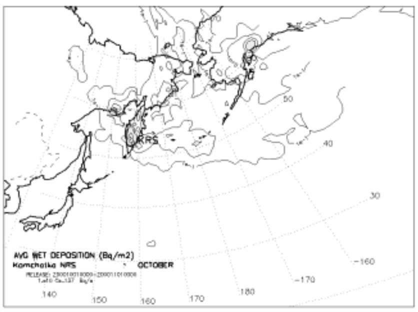

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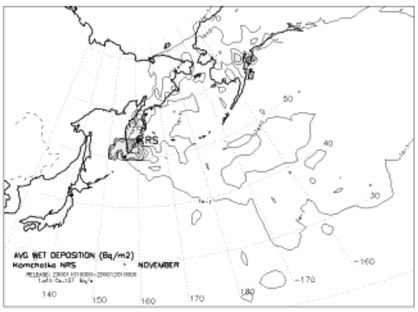

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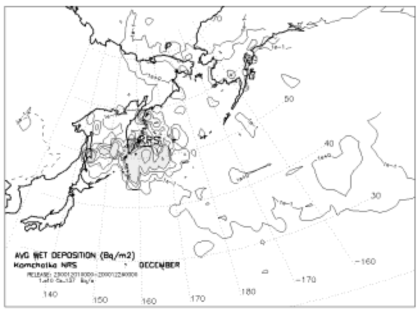

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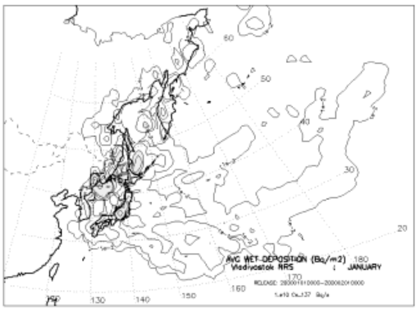

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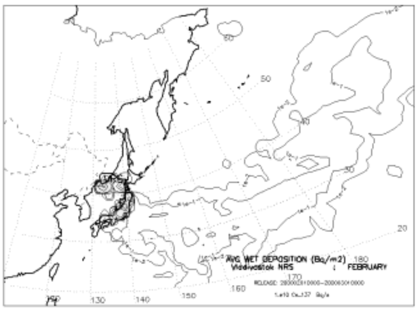

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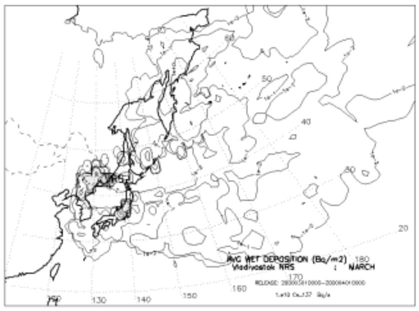

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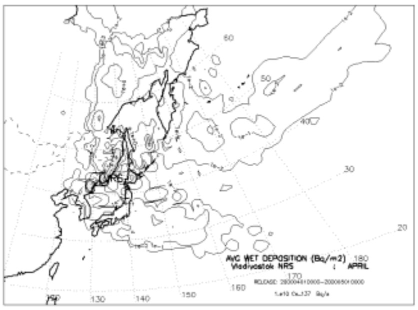

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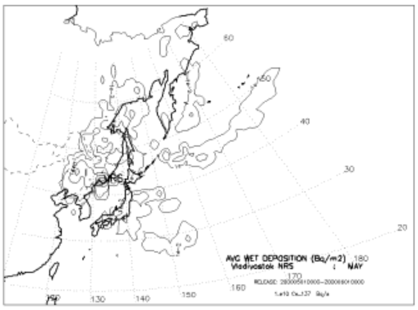

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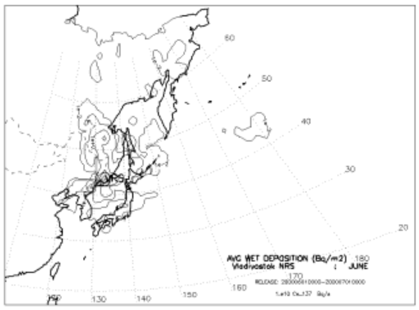

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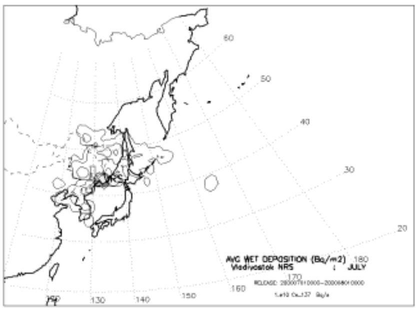

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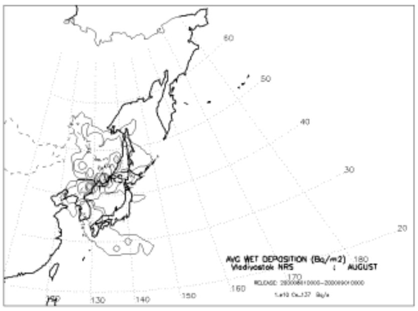

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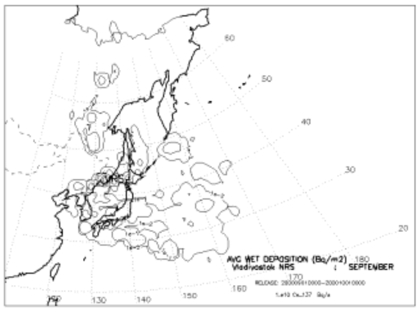

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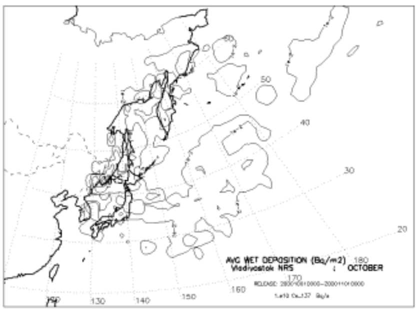

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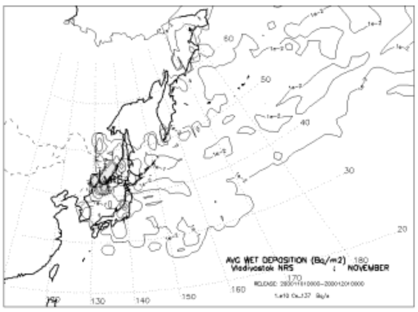

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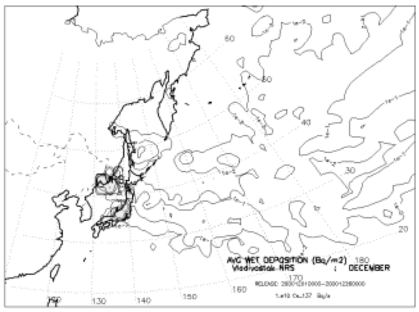

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APPENDIX A

APPROACH TO COMPLEX RADIATION RISK ASSESSMENT APPLYING GIS

Olga Rigina
Prolog Development A/S, Brondby, Denmark

Geographical Information System (GIS) based analyses integrated with mathematical modeling allow to develop a common methodological approach for complex assessment of regional vulnerability and residential risk merging together normally separate ideas: modeling of consequences, probabilistic analysis of airflow patterns, dose estimation, etc. It is particularly useful for evaluating the spatial dependence of risks, by allowing the merging of highly non-homogeneous spatially distributed variables (e.g., population, exposure patterns, etc.).

There are two different approaches (as shown in Figure 1, see e.g. *Rigina, 2001*; *Baklanov et al., 2002*) to perform the complex risk assessment and evaluate the radiation risk (*Rigina & Baklanov, 2002*). The first approach is the probabilistic risk analysis, and the second approach – specific case studies. Both approaches are GIS-based, i.e., all spatial analyses are performed via administrative unit (by county, commune or country involved). Beside the administrative part, the GIS-database contains two parts: the nuclear risk sites database and other GIS layers of interest (demographic, infrastructure and sensitive-institution). Additionally, relevant modeling fields are also converted to new GIS layers for subsequent analysis.

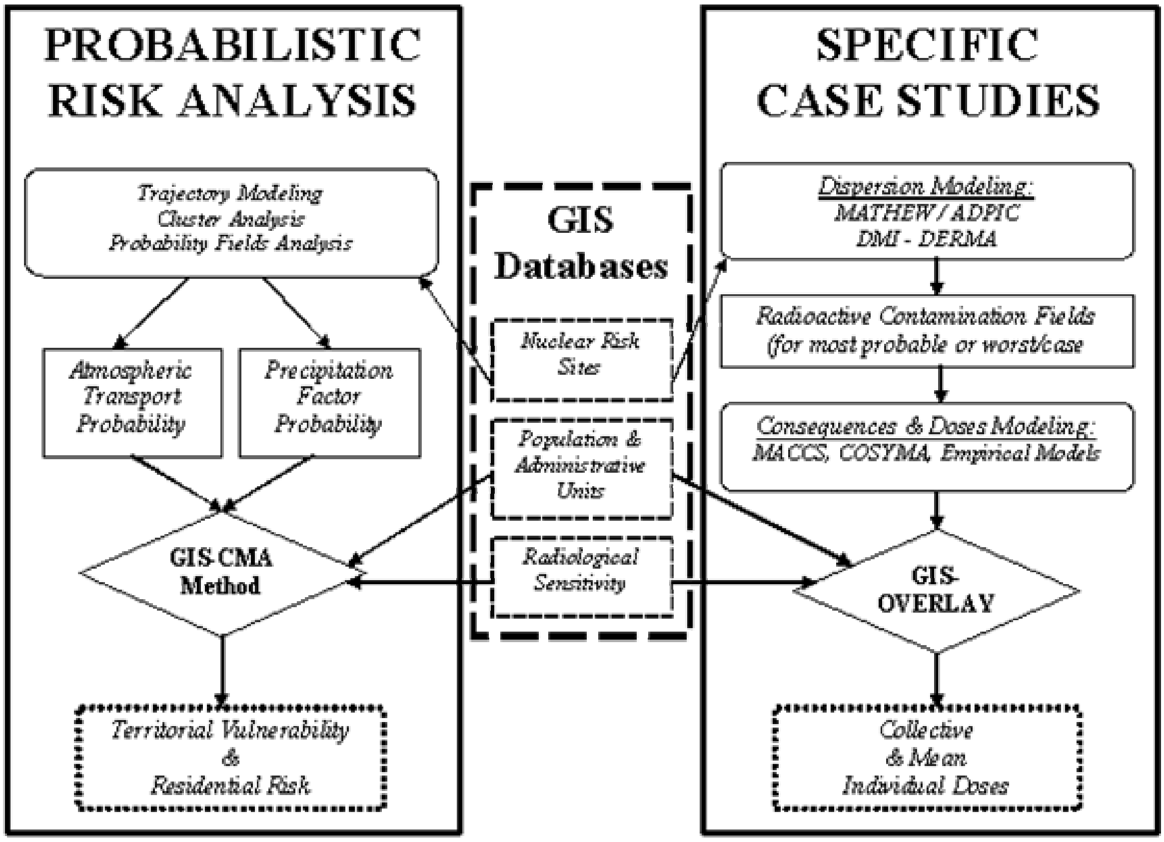


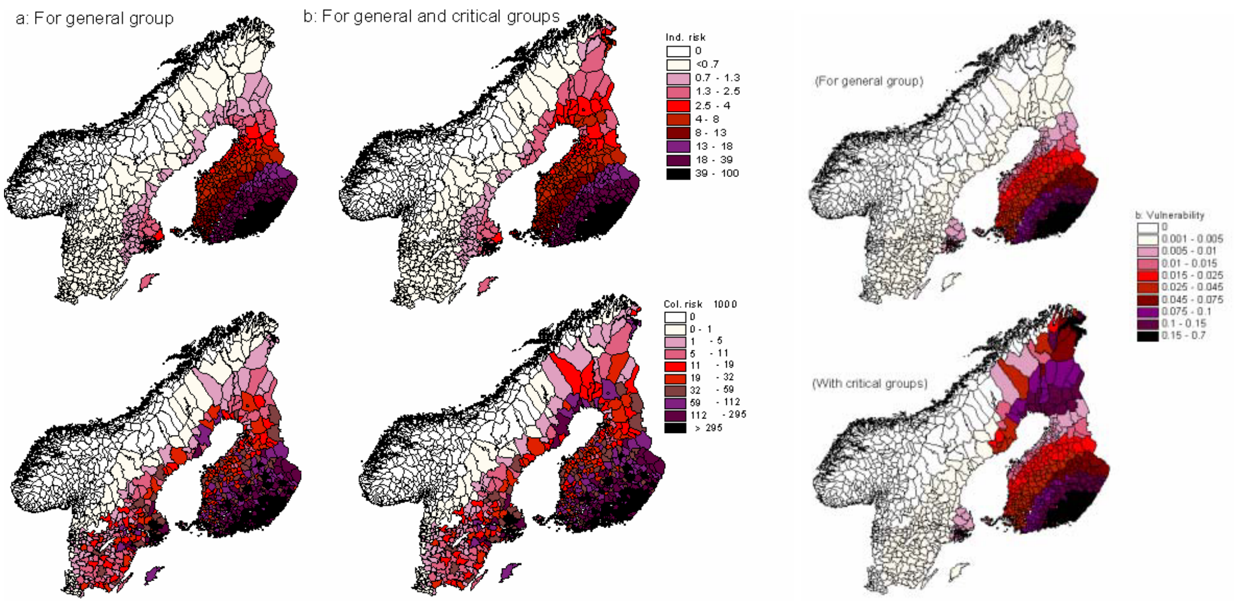
Figure 1. Methodology for complex multidisciplinary risk assessment.

The first approach is the ***probabilistic risk analysis*** (Fig 1, left). This approach is based on the weighted sum of probabilities of atmospheric transport and precipitation combined with factors of radiological sensitivity of territories, population, and administrative units (all after appropriate scaling). The territorial vulnerability and residential risk can be calculated using the Composite Mapping Analysis (CMA) method. This method performs as the GIS overlay method, but applies adding, multiplying, scaling, and weighting of different GIS layers (*Lowry et al., 1995; Obee et al., 1998; Rigina, 2001;Rigina & Baklanov, 2002*). An example of the probabilistic risk maps to the Nordic countries population obtained by the GIS-CMA method application with two different formulations suggested by *Rigina & Baklanov, 2001* is shown in Figure 2.

It should be noted that the probabilities can be estimated by different models depending on available input data, specific needs and modeling 'state-of-art', e.g. trajectory modeling as well as cluster and probability fields analyses on the calculated trajectories for a multiyear period.

The second approach - ***specific case studies*** - is deterministic (Fig 1, right). It predicts consequences in situations of particular interest, e.g., worst-case or most probable situations. The approach applies the GIS overlay method, which involves superimposing modeling fields onto relevant GIS layers (often the same as in the first approach). Applying this method, it is possible to calculate collective and mean individual doses as well as cancer mortality risk for general or specific population groups.

Dispersion modeling, e.g. with MATHEW-ADPIC (*Forster, 1992*) and DMI-DERMA (*Sørensen, 1998*), provides radioactive contamination fields (for most probable or worst-case scenarios), which are further used as input data into consequences and doses modeling with MACCS (*MACCS, 1990*) or other empirical models (e.g. *Bergman & Ågren, 1999*).



Formulation 1 **Formulation 2**

Figure 2. Probabilistic risk maps (based on GIS-CMA method by two formulations, see *Rigina & Baklanov, 2002*) to the Nordic countries population for the Leningrad NPP (*Baklanov et al., 2002*).

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APPENDIX B

APPROACH TO PROBABILISTIC EVALUATION OF SOURCE-RECEPTOR RELATIONSHIP FOR NUCLEAR RISK SITES AND REMOTE TERRITORIES

Alexander Mahura[1,2] & Alexander Baklanov[1]
[1]Danish Meteorological Institute, Copenhagen, Denmark
[2]Institute of Northern Environmental Problems, Kola Science Center

In general, there are two methods to evaluate the source receptor-relationship for air pollutants including radionuclides. Let us define the nuclear risk sites as the source points, and the remote territories (for example, city, administrative unit, country, chosen geographical location of concern, etc.) as the receptor points. The first method is based on statistical analysis of trajectory modeling results for receptor and source points (*Mahura & Baklanov, 2002; Aloyan et al., 2002*). The second method is based on the sensitivity theory and adjoint equations (*Marchuk, 1995; Penenko & Baklanov, 2001*).

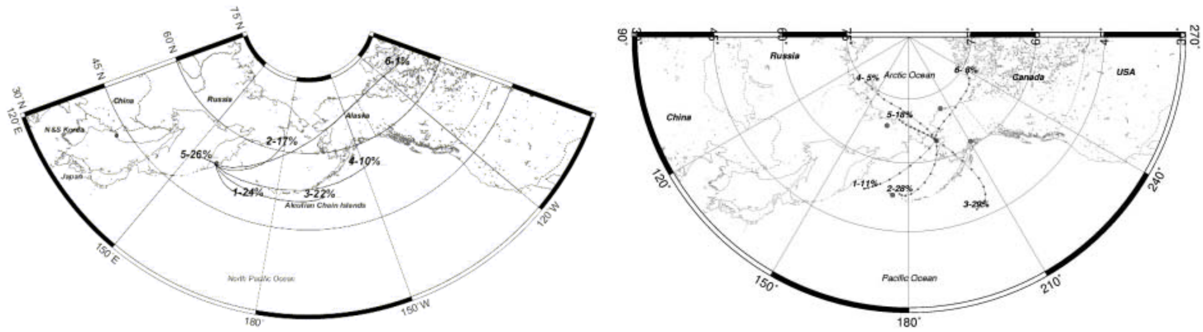
Let us consider the first method in more detail. The first approach in this method is to evaluate the intersections of the averaged atmospheric transport pathways from both source and receptor points. The second approach is to evaluate the intersections of the averaged airflow probability fields constructed for both source and receptor points. To perform such evaluations a set of research tools and a sequence of steps are required. Among these research tools are trajectory models, cluster analysis techniques, and probability fields analysis.

We should note that a detailed description of both approaches is presented by *Mahura & Baklanov, 2002; Aloyan et al., 2002* and methodological aspects of the mentioned research tools is presented by *Mahura, 2001; Baklanov & Mahura, 2001*. The first approach, for example, was used by *Mahura et al., 2002* in the simplest form for identification of source regions: backward trajectories were used to identify the original source region from which a polluted air mass might arrive at the receptor point. Another example (for the second method) of source term estimation based on the sensitivity theory and inverse modeling is presented by *Penenko & Baklanov, 2001*.

In the evaluation process of the first method, initially, for the geographical locations of source and receptor points, the forward and backward trajectories, respectively, are calculated. For this purpose, any type of trajectory model based on different assumptions (isobaric, isentropic, etc) could be applied.

Next, to estimate variability in the atmospheric transport pathways, a set of calculated trajectories is a subject to cluster analysis. These pathways (as shown, for example, in Figure 1) illustrate the general transport patterns from (Figure 1a) or to (Figure 1b) selected locations, reflecting direction and probability of transport within a particular averaged trajectory (or cluster). Each averaged trajectory has its own curvature representing cyclonic or anticyclonic circulation, showing which type of the synoptic system could transport air parcels along the pathway. When these trajectories for source and receptor points intersect each other, we might preliminary estimate bounds (in %) of probability of atmospheric transport from the source to receptor point. The problem is related to the question: what occurs between clusters or mean trajectories? Therefore, we need another approach to extract this "between" information.

Hence, at the third step, to evaluate the intersections of the averaged airflow probability fields for both the source and receptor points, the calculated trajectories are subject to probability fields analysis. The result of this analysis, on example of the Kamchatka (as a source point/site) vs. Nome (as a receptor point/site) is shown in Figure 2.



(a) **(b)**

Figure 1. Summer atmospheric transport pathways a) from Kamchatka NRS, and b) to Nome.

The summer airflow probability fields were constructed for both locations. The prevailing flows of atmospheric transport from the Kamchatka site region are westerlies. The prevailing direction of air parcels arrivals at the Nome site is from the south-west of the site. The intersections of the airflow probability fields isolines showed the significant overlapping of these fields. Hence, the possibility for the air parcels leaving the Kamchatka site region to arrive at the Nome site region is high. Moreover, the rate of overlapping is highest over the south-western parts of the Bering Sea, where it reaches a maximum of 50% of the area of the highest probability of possible impact (AHPPI) from the Kamchatka site, or 50% of the area of the remote potential impact (ARPI) for the Nome site.

Combination of both fields allows identifying the most impact geographical regions, territories, countries, etc. with respect to the source points; and it allows identifying the potential source regions from where the contaminated air masses originated with respect to the receptor points.

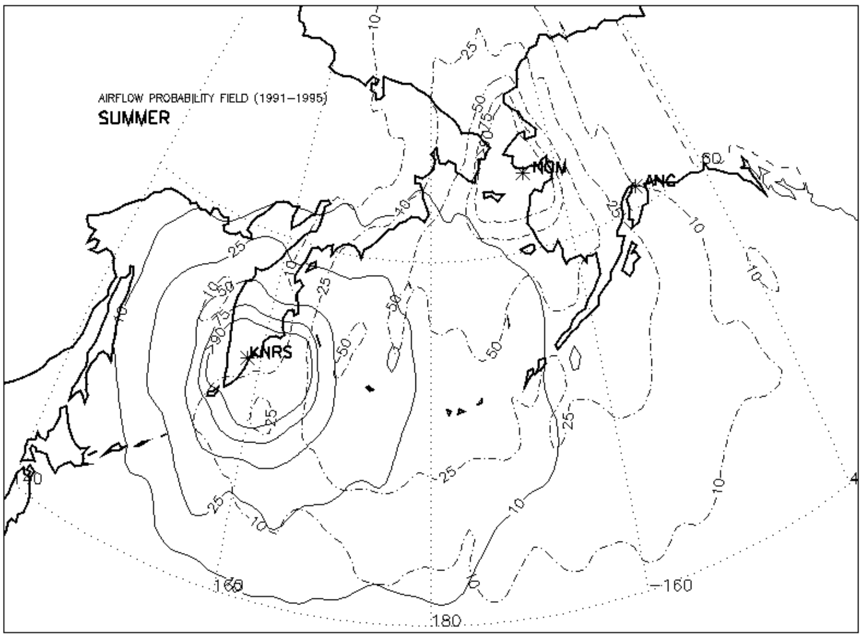


Figure 2. Summer averaged airflow probability fields or sensitivity function for source and receptor points: for Kamchatka NRS vs. Nome.

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APPENDIX C

APPROACH TO PROBABILISTIC ASSESSMENT OF POTENTIAL TERRITORIAL RISK OF CONTAMINATION ON THE LOCAL SCALE

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[1] ***Institute of Northern Environmental Problems, Kola Science Center, Apatity, Russia***

[2] ***Institute Solid Earth Physics, University of Bergen, Norway***

Due to intense development of the world economy, there are many geographical areas oversaturated with imposing risk sources, which represent a threat to both man and environment. Let us consider, for example, some objects of possible radiation hazard (e.g. nuclear power plant, radioactive waste facilities, submarines and ice-breakers) located at the Kola Peninsula (Murmansk Region, Russia). For these objects of radiation hazard, let us focus on hypothetical accidental releases of radioactivity, for simplicity.

Atmospheric Dynamics and Pollution Transport

To evaluate the potential pollution of the studied territories, we applied two research tools. First, for simulation of the atmospheric transport and deposition of radionuclides on the local- and meso-scales, a 3D modeling system was applied (*Aloyan & Baklanov, 1985; Baklanov et al., 1994)*. This system includes a numerical meso-scale meteorological model of the atmospheric thermodynamics for the complex terrain and an Eulerian model for transport, diffusion, and deposition of multi-component radioactive pollutants.

Additionally, typical meteorological and geographic characteristics in the studied region of the nuclear risk object locations have significant influence on the radioactive cloud distribution and subsequent estimation of the radioactive pollution and risk. It should be noted that meteorological conditions, in general, will determine the probability of possible pollution as a result of an accident.

Some individual model blocks, which describe the specificity of the radionuclide atmospheric transport, as well as calculation of the dose loads on the critical organs, correspond to commonly chosen approaches *(Gusev et al., 1991; Techniques, 1987, NRB-99, 1999)*. The traditional methods for dose calculation through different paths of radionuclide arrival into man can be utilized to calculate the exposure levels.

This system was included into the normative-technical document *«Computational methods of distribution of radioactive issues in an environment and radiation doses of the population» (Methods, 1992)*. In particular, it recommended the use of models such as the experts' models for problem solving in conditions of considerable time-multiplexed discontinuity of a wind field, when usage of more conventional and simple models is incorrect.

Probabilistic Risk Evaluation

The second tool is a special program for evaluation of the probabilistic risk (*Morozov et al., 1998*). According to *GOSGORTEHNADZOR, 1996* the definition «Potential Territorial Risk» is qualified as one of the quantitative risk parameters. It means the spatial distribution of the realization frequency of the negative impact at a particular level.

To estimate the expected contamination of the surrounding area due to a possible accident scenario, the probability $P(c>c_{max};\ x,y)$ to exceed some control level of radionuclide concentration

c_{max} at any point *(x,y)* has to be evaluated. The probabilistic approach is based on the Monte-Carlo method in combination with deterministic transport models. The main meteorological factors that govern the radionuclide transport are horizontal wind velocity components - $v_x(t)$ and $v_y(t)$ - at the upper boundary. These parameters are random and their values must conform to probability density functions $p_\pi(x)$ (wind rose) and $p_v(x)$.

The density function is not normalized, because the applied numerical algorithm of random numbers generation with a required density function automatically provides normalization conditions. The change in the wind speed as a function of time is characterized by a normalized autocorrelation function *R(t)*:

$$R(t) = \frac{\int_{-\infty}^{\infty} v(t+\vartheta)\, v(\vartheta)\, d\vartheta}{\int_{-\infty}^{\infty} v^2(\vartheta)\, d\vartheta}$$

As result, the required values of probability of exceeding of c_{max} are determined on the retrieved cumulative distribution functions.

$$P(c \geq c_{\max}; x, y) = \int_{c_{\max}}^{\infty} p(c; x, y)\, dc$$

This scheme was applied to calculate the potential territorial risk for the areas (of 50 km radius) of the Kola nuclear power plant (KNPP) and locations of the nuclear submarines and icebreakers at the Kola Peninsula. Some examples of the probabilistic risk map and probability of exceeding of the control level are shown in Figures 1 and 2, respectively.

It should be noted that this approach can be successfully applied for the sources of the chemical, biological, etc danger. For example, the ore-mining complex (phosphorus production of the APAPIT Company, Kola Peninsula, Russia) had been studied by *Morozov & Fedorenko, 1999,* where the main pollutants released into the atmosphere were fluorides, gaseous miscible, steams of sulfuric and phosphorus acids, dust, SO_2, NO_x, CO.

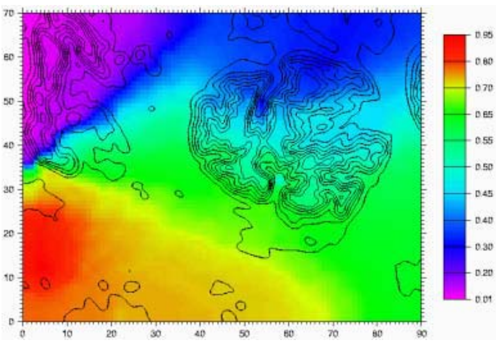
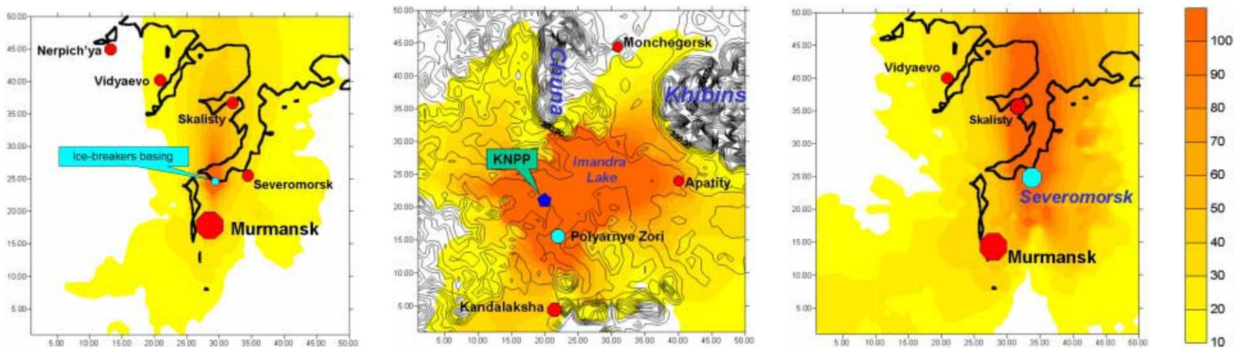


Figure 1. Probabilistic risk map for the Kola NPP where concentration exceeds c_{max} =0.005 Bq/m^3.



Ice-breaker **Kola NPP** **Nuclear submarine**

Figure 2. The probability of exceeding (in %) of the control level for accidents at ice-breaker, nuclear power plant and nuclear submarine.

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