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Generation of wind-series using cumulative probability wind transition matrix—A first order Markov process

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सार — संचयी प्रायिकता की पवन ट्रांजिशन मैट्रिक्स के एक अनुप्रयोग द्वारा विभिन्न प्रकार की ऐसी संभावित पवन सीरीज ज्ञात की जाती हैं जो ऐसे समय बनती हैं जिसके दौरान तेल के अपतटीय फैलाव के खतरे का विश्लेषण किया जाता है। इस विश्लेषण के दौरान, भिन्न-भिन्न समय पर, पवन की विभिन्न संभावित दशाएं उत्पन्न की जाती हैं। समय के माध्यम से, पवन के व्यवहार के अनियमित अनुरूपण के लिए प्रयुक्त की जाने वाली एक विधि में पवन के दीर्घावधि आंकड़ों को पवन की ट्रांजिशन मैट्रिक्स के रूप में प्रयोग किया जाता है। इस शोध पत्र में विभिन्न प्रायिकताओं की पवन सीरीज के निर्माण के लिए, संचयी प्रायिकता की पवन ट्रांजिशन मैट्रिक्स के उपयोग और विधि का उल्लेख किया गया है।

ABSTRACT. One application of the cumulative probability wind transition matrix is to determine the various probable wind series that might occur, during the period for which offshore oilspill risk is to be analysed. During this analysis we have to generate different probable wind conditions at different instances of time. One of the methods to simulate the random wind behaviour through time, is to use historical wind data presented in the form of wind transition matrix. This paper highlights the methodology and use of the cumulative probability wind transition matrix in generating the different probable wind-series.

Key words — Transition matrix, Wind series, Markov process.

1. Introduction

For risk analysis the winds are modelled by generating the wind transition matrix (Mascarenhas *et al.* 1991) to obtain several wind series. It is assumed that wind can be modelled as a first order Markov process, in which likelihood of wind speed and direction in the next interval depends only on the current wind speed and direction. Hence the variations in the wind is represented as a first order Markov process, *viz.*, the wind in one time-step is a random function of the wind in the previous time-step. The individual elements of the percentage cumulative wind transition matrix are the probabilities that a particular wind velocity will be succeeded by another wind. The longer the historic data set, better will be the resolution of the cumulative probability wind transition matrix. The wind-series were obtained from the cumulative probability wind transition matrix, which was constructed from the historic wind record. This was obtained by the wind monitoring system developed at the National Institute of Oceanography.

2. Methodology

We assume that, we have a sequence of trials with following properties. The outcome of each experiment is one of a finite number of possible outcomes a_1, a_2, ..., a_r. It is assumed that the probability of outcome a_j on any given experiment is not necessarily independent of the outcomes of previous experiments but depends at most upon the outcome of the immediately preceding experiment. We assume that there are given numbers p_{ij} which represent the probability of outcome a_j on any given experiment, given that the outcome a_i occurred on the preceding experiment. The outcomes a_1, a_2, ..., a_r are called the state space of the system and the numbers p_{ij} are called transition probabilities. If we assume that the process begins in some particular state, then we have enough information to determine the true measure for the process and can calculate probabilities of statements relating to the overall sequence of experiments. A stochastic (John *et al.* 1974) process of the above kind is called a Markov chain process.

The transition probabilities can be arranged in a matrix p which is written as :

$$p = \begin{vmatrix} p_{11} & p_{12} & \cdots & p_{1r} \\ p_{21} & p_{22} & \cdots & p_{2r} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ p_{r1} & p_{r2} & \cdots & p_{rr} \end{vmatrix}$$

This matrix is called the transition matrix of the Markov process, which is a stochastic matrix.

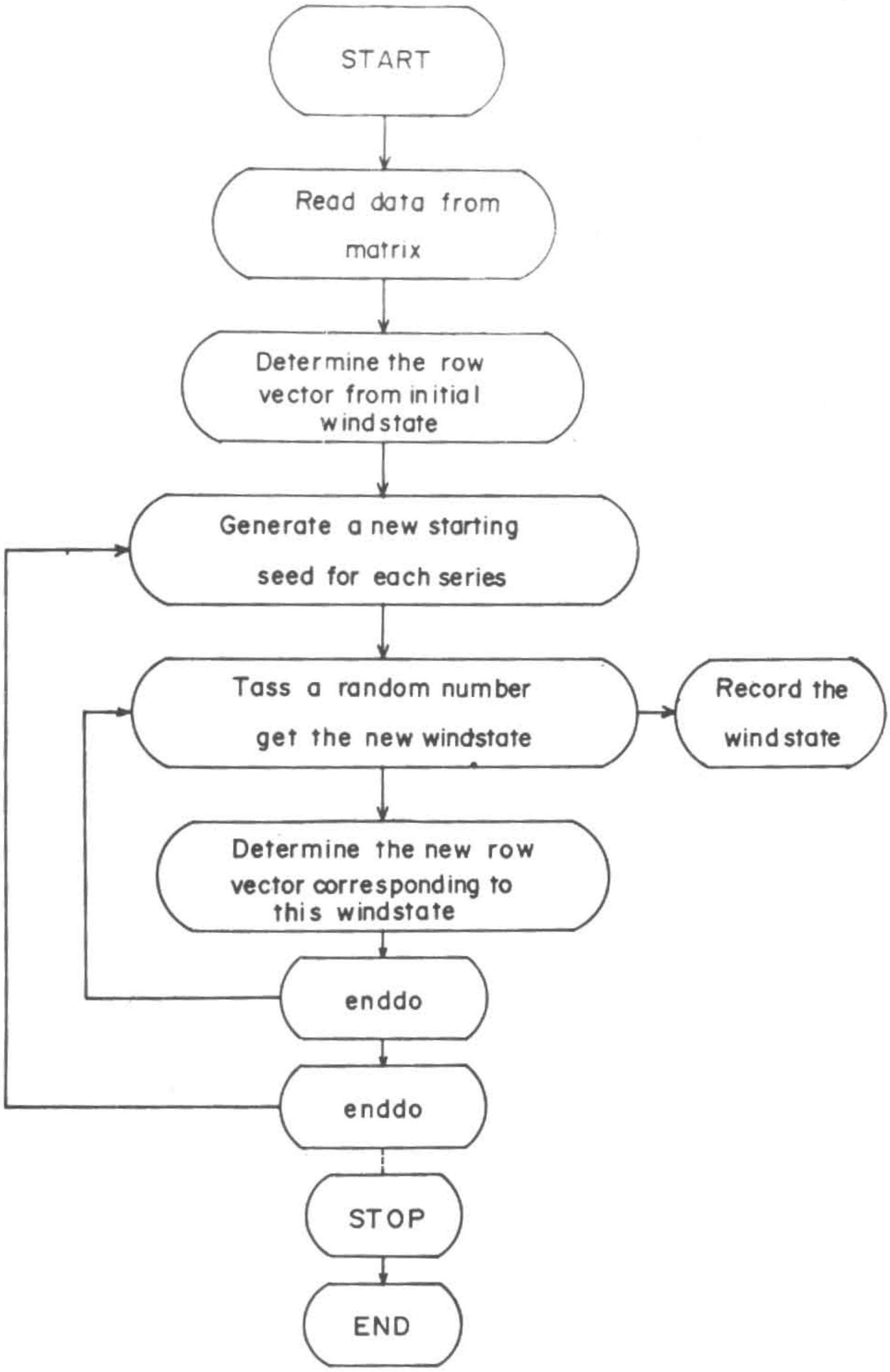

Fig. 1. The flow chart of wind model

The wind transition matrix of the Markov process has been constructed from the historic wind record. This process consists of 49 states (Mascarenhas *et al.* 1992), *i.e.*, each of the 8 wind directions (N, NE, E, SE, S, SW, W, NW) are further categorised into 6 different sub-groups depending on the wind speeds. All the wind speeds of intensity < 0.2 m sec^{-1} irrespective of the direction have been grouped as calm. The sampling interval used to obtain the transition matrix is three minutes. If the system is in the state a_i then the ith row vector represents the probabilities of all the possible outcomes of the next trial. The components of this

TABLE 1

Probable wind series 1

Seed 2	Random 2	Wind speed	Wind direction
51691	.8216248	4.00	270
280644288	.6074033	4.00	270
−1095536679	.5990019	4.00	270
861088518	.9878345	4.00	315
1925160023	.9598522	6.00	315
2038347548	.0442986	4.00	360
−1941869851	.5039682	4.00	360
1733304450	.0501723	.20	−1
−163472637	.3921776	.20	−1
1565297848	.1386952	.20	−1
−1738248143	.9830618	4.00	315
−906005186	.0490642	4.00	360
−964587025	.3759251	1.50	360
−1177811052	.9037766	1.50	315
870116285	.6100130	1.50	315
−602700486	.7672248	1.50	315
704154907	.2699814	1.50	270
336110512	.7355390	4.00	270
−617117303	.2476149	1.50	270
−255333258	.3076816	4.00	225

(Seed 1 = 48483. random 1 = .5169182)

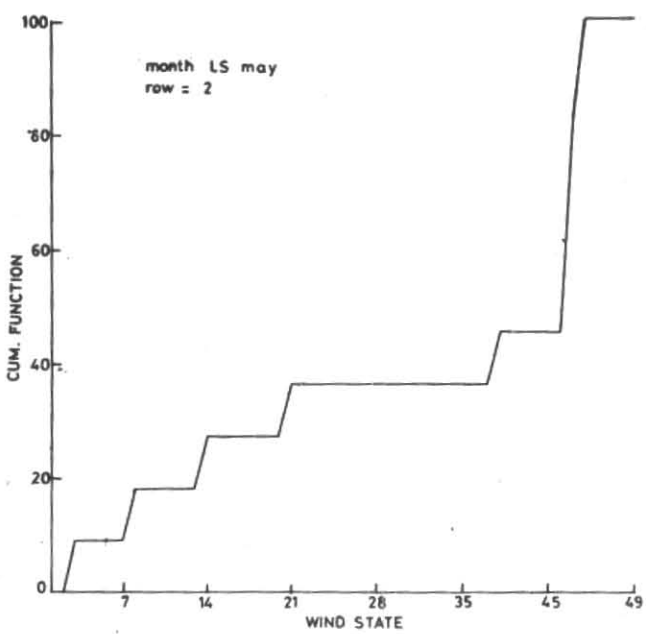

Fig. 2. The cumulative probability distribution

vector are non-negative and the sum is 1 and hence it is a probability vector. The variation in the wind is represented as a first order Markov process. wherein the wind in one time step is a random function of the wind in the previous time-step. The individual elements of the percentage cumulative wind transition matrix are

TABLE 2

Probable wind series 2

Seed 2	Random 2	Wind speed	Wind direction
35541	.0133295	1.50	360
192965938	.3724914	4.00	135
−359928973	.2621956	.20	−1
155739112	.4664464	.20	−1
−600904415	.3441076	.20	−1
1865089774	.1669154	.20	−1
−1960487073	.1904011	.20	−1
−555345980	.6940522	4.00	315
93730221	.0161028	1.50	360
2055242730	.4286551	1.50	270
−412239989	.1753998	4.00	225
−372925216	.2520108	1.50	225
−1681387399	.1733580	1.50	45
−1446671322	.1669879	1.50	45
1516591095	.5838909	1.50	135
120762172	.9503808	1.50	270
−1512150651	.6239786	1.50	270
−1783367774	.5865035	1.50	270
−1047346013	.1341362	4.00	225
495209176	.2320333	1.50	225

(Seed 1 = 263228056. random 1 = .3554158)

the probabilities that a particular wind velocity will be succeeded by another wind.

Different probable wind series using the cumulative probability wind transition matrix for the month of May (Mascarenhas *et al.* 1992) have been obtained. The graph of the cumulative probability distribution for the 32nd row is shown in Fig. 2. The wind model has been developed in Fortran-77, on the ND-570 system. The flow chart is shown in Fig. 1. Given the starting wind speed and wind direction, the model generates the probable wind series that might occur in the next time-step. To generate the wind series the starting wind state is taken and the corresponding row of the matrix is obtained by generating random number (between 0 & 1), thus obtaining the corresponding value on that row (Fig. 2) which is closer to this random number. This value gives the windstate for the next instance. which is the first element of the wind series. The previous value obtained is used as a seed to generate the next element of the wind series. This procedure is continued to obtain other elements of the wind series.

3. Results and discussion

Tables 1 and 2 show two probable wind series of twenty elements each for the month of May with starting wind direction as 270 deg., starting wind speed 1.20 m/sec. This methodology can be used to generate any number of wind series containing any number of elements. If the starting conditions, *viz.*, the starting wind speed and direction are changed keeping the seed constant, then we shall obtain a different set of probable series. A different set of series can also be obtained by changing the starting seed. With this method we can simulate the random wind behaviour through time by using the historical wind data presented in the form of cumulative probability wind transition matrix.

4. Conclusion

These different wind series are the most likely states that might occur in the next time step and hence any individual series cannot be compared with the climatological wind series. This methodology of generating wind series could be used to study different scenarios and impact assessment like oilspill risk analysis.

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