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June 11, 2001
Contract No. NRC–02–97–009
Account No. 20.01402.461

U.S. Nuclear Regulatory Commission
ATTN: Mrs. Deborah A. DeMarco
Office of Nuclear Material Safety and Safeguards
TWFN Mail Stop 8 A23
Washington, DC 20555

Subject: Submittal of Poster—Probabilistic Modeling of the Dispersion and Accumulation of Volcanic Ash Using a "Not-So-High Performance" PC Cluster

Dear Mrs. DeMarco:

Attached is a poster for presentation at the Society for International and Applied Mathematics (SIAM) conference in Boulder, Colorado. This poster is based on work done by Nathan Franklin, Charles Connor, and others. The poster describes the application and evaluation of a Beowulf Pentium Cluster to modeling of volcanic ash fall. The abstract for the poster, Probabilistic Modeling of the Dispersion and Accumulation of Volcanic Ash Using a "Not-So-High Performance" PC Cluster, was approved by NRC in an e-mail from J. Trapp on February 26, 2001. This poster will be presented at the SIAM conference on mathematical and computation issues in the geosciences on June 11, 2001, in Boulder, Colorado.

If you have any questions please contact Dr. Brittain Hill at 210-522-6087 or me at 210-522-5252.

Sincerely,

Budhi Sagar
Technical Director

rae
Attachment

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Probabilistic Modeling of the Dispersion and Accumulation of Volcanic Ash Using a "Not-So-High-Performance" PC Cluster

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Abstract

Numerical models to estimate tephra (volcanic ash) deposition from volcanic eruptions are useful tools for hazard and risk assessments. Here, we present an empirical model and computer code for tephra deposition. The computer program, written in C, takes sets of input parameters that describe the characteristics of an eruption, or representative set of eruptions, and computes the deposition of tephra at a user-specified location, or over an area. The original model, based on Suzuki (1983), abstracted the wind during the eruption using a single wind speed and direction. Here, this model is extended to include a stratified wind field that more realistically represents meteorological conditions. A large number of eruptions must be simulated in probabilistic forecasting of tephra accumulation. To address the long execution time of such an operation, the code was written using Parallel Virtual Machine libraries for execution in parallel on an inexpensive PC cluster. This approach is particularly effective because the model lends itself to the division of data into independent partitions for parallel computing. With the parallel code, we achieve excellent speedup, an important result for the computationally expensive task of probabilistic tephra dispersion modeling. This approach should be generally applicable to geologic hazard and risk assessments.

Tephra Deposition Model

Tephra is a common product of volcanic eruptions. Tephra is dispersed downwind of erupting volcanes, sometimes to distances of 100's to 1000's of kilometers. Tephra accumulation results in building collapse, causes adverse health effects, and disrupts infrastructure.

As the magnitude of the eruption and meteorologic conditions during eruptions are not known in advance, stochastic simulations are used to develop probabilistic estimates of tephra accumulation. For example, P[tephra < 1 cm at x, y | magnitude of volcanic eruption] (Hill et al., 1998; Connor et al., 2001).

One model developed for modeling tephra dispersion (Suzuki, 1983)

$$X(x,y) = \int_{\phi_{min}}^{\phi_{max}} \int_0^H \frac{5 f_Z(z) f_\Phi(\phi) Q}{8\pi C (t+t_s)^{5/2}} exp[-\frac{5((x-ut)^2+y^2)}{8C(t+t_s)^{5/2}}] dz d\phi \qquad (1)$$

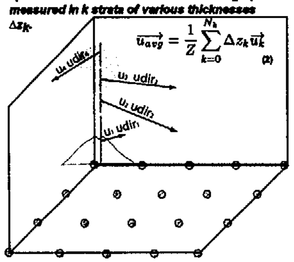
where:

- $X(x,y)$ = tephra accumulation (gm/cm^2)
- x,y = geographic location with respect to the volcanic vent
- $f_Z(z)$ = probability density function for tephra diffusion out of the column
- H = column height
- $f_\Phi(\phi)$ = probability density function for grain size
- Q = total mass erupted
- u = wind speed in the x-direction
- t = tephra particle fall time
- t_s = tephra diffusion time
- C = eddy diffusivity in the atmosphere
- ϕ = particle size

Wind Stratification

Suzuki (1983) was modified to include wind speed and direction as a function of height, measured in k strata of various thicknesses Δz_k.

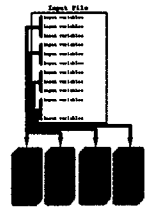
$$\overrightarrow{u_{avg}} = \frac{1}{Z}\sum_{k=0}^{N_k} \Delta z_k \overrightarrow{u_k} \qquad (2)$$



Parallel Implementation

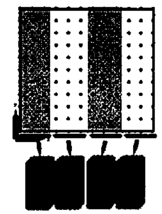
Stochastic simulations were done on a low-cost Beowulf cluster, comprised of eight Pentium II processors (200 MHz), and one Pentium III (450 MHz) processor serving as the Master node.

Equation 1 was implemented in C and parallelized using both the Message Passing Interface (MPI) and Parallel Virtual Machine (PVM) libraries. Two domain decomposition techniques were used.



Input Decomposition

Eruption parameters and windfield characteristics sent to individual slave nodes, tephra accumulation calculated for point or entire grid.

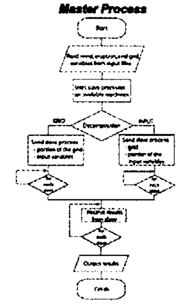


Grid Decomposition

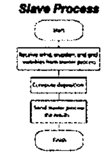
Same eruption parameters and windfield characteristics sent to several nodes that each estimate tephra accumulation for a section of the area around the volcano.

Computational Procedure

Master Process



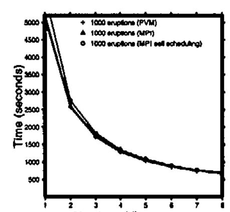
Slave Process

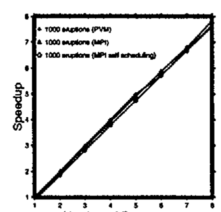


An even distribution and a self-scheduling distribution were implemented. In the even distribution, the computational domain is divided equally among nodes at the outset. In the self-scheduling distribution, small portions of the computational domain are allocated to nodes throughout execution.

Performance

Cluster performance was tested using a suite of 1000 simulations of Eq (1), using only 200 MHz nodes. Execution time and speedup was quite similar for MPI and PVM. Self-scheduling was only slightly less efficient for the homogeneous cluster. These results indicate the parallel tephra accumulation application scales nearly linearly and efficiently uses the available computational resources.

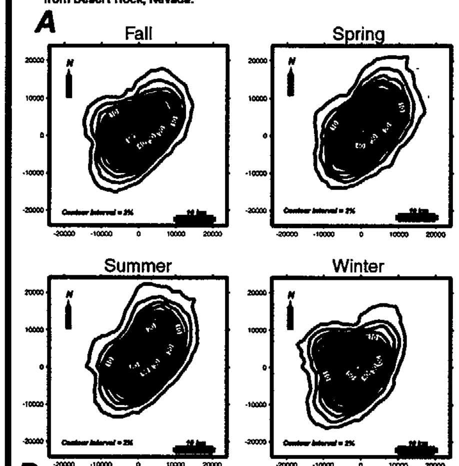




Speedup = Serial Execution Time / Parallel Execution Time

Application

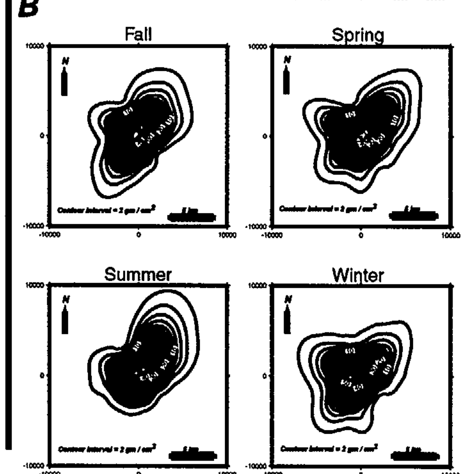
We applied this parallel model to a volcanic hazard assessment for potential small-volume basaltic eruptions through the proposed high-level radioactive waste repository at Yucca Mountain, Nevada, as part of an overall risk assessment for the site. A range of typical eruption magnitudes were used together with upper air data from Desert Rock, Nevada.



Simulations were run for 1000 eruptions to produce maps of P[tephra accumulation > 1 cm | eruption] using the eruption parameters given below. These maps (A) were prepared using seasonal windfield data.

Eruption parameters

- volume of deposit = 4 - 50 x 10^6 m^3
- mean particle diameter = 0.0 phi
- std. dev. of particle diameter = 0.0 phi
- tephra diffusion parameter = 0.1 - 0.5
- muzzle velocity = 4000 - 10000 cm/s
- column height = 2.0 - 7.0 km
- particle density = 0.89 - 1.6 gm/cm^3
- particle shape factor = 0.5



A second set of simulations (B) was run for a single eruption lasting one month. Total depostion for this eruption is shown for each season.

Eruption parameters

- volume of deposit = 2 x 10^7 m^3
- mean particle diameter = 0.0 phi
- std. dev. of particle diameter = 0.0 phi
- tephra diffusion parameter = 0.18
- muzzle velocity = 2148 cm/s
- column height = 3.73 km
- particle density = 0.9 gm/cm^3
- particle shape factor = 0.5

Conclusions

Parallel computation of tephra dispersion is an efficient method for probabilistic assessment of hazard from tephra deposition. Speedup was nearly linear, with no significant differences observed between MPI and PVM. Self-scheduling with MPI led to a slight decrease in efficiency, that would likely be offset in heterogeneous clusters. Stochastic simulation in parallel should be generally applicable to many types of volcanic hazard, such as lava flows and lahars.

References

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Hill, B.E., C.B. Connor, M. Jarzemba, P. La Femina, M. Navarro, and W. Strauch, 1998, 1995 eruptions of Cerro Negro Volcano, Nicaragua, and risk of future eruptions, Geological Society of America Bulletin, 110: 1231-1241.

Suzuki, T., 1983, A theoretical model for the dispersion of tephra. In, Arc Volcanism: Physics and Tectonics, D. Shimozuru and I. Yokoyama, eds. Terra Scientific Publishing, Tokyo, 95-103.

Acknowledgements: This presentation documents work performed at the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC) under contract No. NRC-02-97-09. The activities reported were performed for the NRC Office of Nuclear Material Safety and Safeguards, Division of Waste Management. This presentation is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.