OCEAN
modelling

ISSUE 107

JUNE 1995

FEATURING:

ISAYEV - Towards A Local Diagnostic Method

DELEERSNIJDER, OZER and TARTINVILLE - A Methodology For Model Intercomparison: Preliminary Results

SALUSTI and SERRAVALL - On The Conversation Of Potential Vorticity For Viscous Currents

A METHODOLOGY FOR MODEL INTERCOMPARISON: PRELIMINARY RESULTS

Eric Deleersnijder, José Ozer and Benoît Tartinville

INTRODUCTION

Over recent years the intercomparison of shallow sea model results has been performed in different domains of interest, e.g. the North Sea (Peeck et al., 1983; de Vries, 1992; de Vries et al., 1995), the Adriatic Sea (de Vries et al., 1995), the Aegean Sea (de Vries et al., 1995), the English Channel (Jamart and Ozer, 1989; Werner, 1989, 1995), the plume of the Rhine River (Ruddick et al., 1995) or the Halten Bank area, off Norway (Hackett and Roed, 1994).

All of these exercises followed relatively similar procedures. First, the model runs to be carried out were defined so that the models had sufficiently similar computational domains and forcings. Second, the distance between the model results - and, in most cases, between the model results and the observations - was evaluated according to various norms. Finally, attempts were made to identify the reasons for the discrepancies between the model results.

It seems that the first and second tasks were generally carried out successfully. The third stage, however, did not always lead to detailed or useful conclusions. One of the reasons underlying this partial failure was obviously the difficulty to link cause and effect when dealing with complex, non-linear models. In view of these difficulties, we have decided to seek techniques that could facilitate the understanding of the discrepancies between model results. Here, we provide a preliminary analysis of the potential for intercomparison studies of the "factor separation method", which was devised by Stein and Alpert (1993) in the scope of meso-scale atmospheric modelling.

AN INTERCOMPARISON METHOD

One of the most popular approaches for understanding how a given model is working consists in performing sensitivity studies. The latter may be performed in an extremely elegant and rational way by resorting to the method of Stein and Alpert (1993), which is outlined below.

In the governing equations, or in the forcings, switches may be introduced, so that appropriate terms may be "turned on" or "turned off". Hereafter, the switches are denoted s_i $(i = 1, 2, ..., n)$. When a given switch is zero, the corresponding term is disabled, and when the switch is equal to 1, the corresponding term is active.

Here, we assume that switches may act on any kind of terms, be they part of the initial conditions, the boundary conditions or the governing equations. Stein and Alpert (1993), however, seem to adopt a more restrictive way of introducing switches.

Every quantity ψ considered in the analysis of the model results may be regarded as a function of the switches, i.e. $\psi = \psi(s_1, s_2, ..., s_n)$. The method may be applied whether or not ψ depends on time or space coordinates.

If there is only one switch, $\psi(1)$ is associated with the results obtained when the phenomenon concerned by the switch is present. Conversely, if the relevant process is disabled by setting the switch to zero, the variable ψ then reads $\psi(0)$. We may write

$$\psi(1) = \psi(0) + \Delta\psi(1), \tag{1}$$

where $\Delta\psi(1) = \psi(1) - \psi(0)$ is a measure of the role of the process in which we are interested. Obviously, to evaluate the sensitivity of the model results to a given phenomenon, i.e. to compute $\Delta\psi(1)$, 2 runs of the model must be performed.

Computing $\Delta\psi(1)$ is typical of a model sensitivity study where the influence of one single process is examined. If several processes need to be considered at a time, say 2 for simplicity, one may compute $\Delta\psi(1,0) = \psi(1,0) - \psi(0,0)$ and $\Delta\psi(0,1) = \psi(0,1) - \psi(0,0)$. Nonetheless, in general, one may not write $\psi(1,1) = \psi(0,0) + \Delta\psi(1,0) + \Delta\psi(0,1)$, since the response of the model is unlikely to be linear. This is the stumbling block of certain sensitivity studies. Stein and Alpert (1993) suggested overcoming this difficulty by taking into account the "synergistic term", defined to be $\Delta\psi(1,1) = \psi(1,1) + \psi(0,0) - \psi(1,0) - \psi(0,1)$, so that

$$\psi(1,1) = \psi(0,0) + \Delta\psi(1,0) + \Delta\psi(0,1) + \Delta\psi(1,1). \tag{2}$$

The synergistic term $\Delta\psi(1,1)$ may be regarded as a measure of the interactions between the two processes considered. As was shown by Khain et al. (1993), the synergistic term may be much larger than the classical sensitivity measures, $\Delta\psi(1,0)$ and $\Delta\psi(0,1)$. In such a situation, it would be foolhardy to deal with the classical sensitivity estimates only.

If the influence of 2 phenomena is investigated, 4 model runs are needed. When 3 processes are concerned, it is necessary to produce 8 sets of model results. In general, 2^n runs must be carried out. Whatever the number of phenomena considered, the model response may alway be written in terms of quantities obeying a simple additive principle that holds true in spite of the possible non-linearity of the model. The generalisation of expressions (1) and (2) may be found in Stein and Alpert (1993).

The choice of the processes to be singled out is crucial. Some choices may obviously lead to irrelevant results. In addition, the sensitivity of the model results to a given phenomenon depends on the whole set of phenomena on which switches are acting (Alpert et al., 1995).

We suggest applying the factor separation method in the framework of model intercomparison exercises. One would analyse the sensitivity of each model to a series of processes or forcings. A thorough analysis of the $\Delta\psi$'s would certainly help explaining the reason of the discrepancies between the models considered. Such an approach is illustrated below.

ILLUSTRATION

The usefulness of the factor separation technique for model intercomparison is illustrated with the help of MUMM's operational North Sea model (Adam, 1987). If η and $\mathbf{u}$ represent the sea surface elevation and the depth-averaged horizontal velocity, the equations of the model read

$$\frac{\partial \eta}{\partial t} + \nabla \cdot (H\mathbf{u}) = 0, \tag{3}$$

$$\frac{\partial \mathbf{u}}{\partial t} + s_1 \mathbf{u} \cdot \nabla \mathbf{u} + f \mathbf{e}_z \times \mathbf{u} = -g\nabla\eta + \frac{\tau^S - s_2 \tau^b}{H} + A\nabla^2 \mathbf{u}, \tag{4}$$

where t is time; ∇ denotes the "gradient operator"; f, $\mathbf{e}_z$, g and $A(= 10^4 \text{ m}^2 \text{ s}^{-1})$ represent the Coriolis factor, the vertical unit vector, the gravitational acceleration and the horizontal viscosity, respectively; H is the sea depth, while τ^S and τ^b stand for the specific surface and bottom stresses.

In all the simulations carried out here, the wind stress is neglected, i.e., $\tau^S = 0$. The flow in the computational domain is forced by prescribing the M2 tide elevation – which is the dominant tidal component in the North Sea – along the open sea boundaries. Each model run is carried out until a periodic regime is established.

The variable we are going to examine, i.e. ψ, is the amplitude of the M2 tide, obtained from a Fourier analysis of the model results. Thus, ψ is a time-independent quantity ensuing from the post-processing of the model results. It is also worth bearing in mind that ψ is a positive definite quantity, i.e. $\psi \geq 0$.

It is decided to investigate the respective roles of momentum advection and bottom friction. Accordingly, the switches s_1 and s_2 – pertaining to advection and bottom friction, respectively, – are introduced into the momentum equation (4).

To have different models, two versions of MUMM's model – hereafter referred to as A and B – are set up. The model A is that which is used in operational forecasting: the advection of momentum is discretised by a first-order upwind scheme and the bottom stress is computed as

$$\tau^b = C_D \mid \mathbf{u} \mid \mathbf{u}, \tag{5}$$

where the bottom drag coefficient C_D is 2.40×10^{-3} in the English Channel and the Southern Bight, and is taken to be 2.04×10^{-3} in the rest of the computational domain. The model B is similar to A, except that the momentum advection is computed according to a second-order, centered scheme. In addition, the bottom stress is still parameterized by (5), but the drag coefficient is 2.32×10^{-3}, $g/(25 + H)^2$ and 1.21×10^{-3}, if $H \leq 40$ m, $40 < H \leq 65$ m and 65 m $< H$, respectively (Verboom et al., 1992).

In a "real-world" model intercomparison study, the models dealt with are generally so different that they are unlikely to provide similar results even when all switches are set to zero. To place ourselves in a similar situation, we have further modified the model B, by adding 5 meters to the unperturbed sea depth used in A. In other words, we have resisted the temptation of cheating by preventing $\psi^A(0,0)$ from being equal to $\psi^B(0,0)$...

When analysing the model results, use is made of the operator "<>", denoting the average over the computational domain.

Since

$$\frac{<\mid \psi^A(1,1) - \psi^B(1,1) \mid>}{(<\psi^A(1,1)> + <\psi^B(1,1)>)/2} = 0.19, \tag{6}$$

the results of the complete models are significantly different. That $<\psi^A(1,1)>$ (= 1.2 m) is somewhat smaller than $<\psi^B(1,1)>$ (= 1.4 m) may indicate that there is more damping in A.

The space structures of ψ^A (1, 1) and ψ^B (1, 1), depicted in Figs. 1 and 2, exhibit some discrepancies, the interpretation of which is quite difficult.

The ratios

$$\left(\frac{<\mid \Delta\psi^A(1,0) \mid>}{<\psi^A(0,0)>}, \frac{<\mid \Delta\psi^B(1,0) \mid>}{<\psi^B(0,0)>} \right) = (0.25, 0.022) \tag{7}$$

imply that A is much more sensitive to advection than B, which, at first, may seem surprising, since the Rossby number of the flow is of order 0.02 – if the velocity and space scales are taken to be 0.5 m s^{-1} and 250 km, respectively. It may be deemed reassuring that $<\mid \Delta\psi(1,0) \mid> / <\psi(0,0)>$ is of the same order of magnitude as the Rossby number for model B, while it is worrying that this ratio is about

10 times larger for model A. That the model A is overly sensitive to advection is most probably due to the first-order upwind discretization of the momentum advection. Carrying things to extremes, one might say that, in model A, the advection terms are, in fact, dissipative terms. This is somewhat confirmed by $< \Delta\psi^A(1,0) >$ being negative, because advection reduces the amplitude of the tidal elevation.

On the other hand, we have

$$\left(\frac{<|\Delta\psi^A(0,1)|>}{<\psi^A(0,0)>}, \frac{<|\Delta\psi^B(0,1)|>}{<\psi^B(0,0)>}\right) = (0.59, 0.42), \tag{8}$$

implying that the effect of the bottom friction is slightly more important in A than in B, which is not surprising since, at most locations, the bottom drag coefficient is larger in A than in B. Nonetheless, in A and B, C_D is of the same order of magnitude, which is in agreement with the ratios (8) being also of the same order of magnitude.

The synergistic terms are

$$\left(\frac{<|\Delta\psi^A(1,1)|>}{<\psi^A(0,0)>}, \frac{<|\Delta\psi^B(1,1)|>}{<\psi^B(0,0)>}\right) = (0.25, 0.017). \tag{9}$$

The relative smallness of the synergistic term of model B obviously ensues from the advection being truly negligible. For model A, however, it is conceivable that the synergistic term is significant because the bottom stress obeys a non-linear parameterization while the damping effect of advection and bottom friction is of equivalent importance.

CONCLUSION

A more profound analysis of the present numerical experiments will be given in Deleersnijder et al., (1995). Nevertheless, at the present stage, a useful – though preliminary – conclusion may be drawn. It is believed that the factor separation method offers relevant guide lines for performing intermodel sensitivity experiments, which are necessary to identify the very reasons of the discrepancies between the results of different models. In the example above, the discretization of the advection term of model A is shown to be inappropriate – in spite of the smallness of the Rossby number, which might have lead one to believe that advection is, in any case, unimportant. This problem could not have been identified by simply looking at crude model results, i.e. $\psi^A(1,1)$ and $\psi^B(1,1)$ as would have been done in a simple model intercomparison exercise.

ACKNOWLEDGEMENTS

ED is a Research Associate with the National Fund for Scientific Research of Belgium. This work is carried out in the scope of the NOMADS (**NO**rth Sea **M**odel **A**dvection **D**ispersion **S**tudy) project, which is funded by the European Union Marine Science and Technology Programme, as a "Concerted Action" in the field of numerical modelling of marine systems (under contract MAS2-CT94-0105). ED is indebted to Professor A. Alpert for the encouragements and suggestions he provided.

REFERENCES

ADAM, Y., 1987: The New Version of the MU-STORM Model, *MUMM Technical Report*, 23 pp. (+ figures).

ALPERT, P., TSIDULKO, M., and STEIN, U., 1995: Can sensitivity studies yield absolute comparisons for the effects of several processes? *Journal of the Atmospheric Sciences*, **52**, 597–601.

DELEERSNIJDER, E., OZER, J., and TARTINVILLE, B., 1995: A methodology for understanding the discrepancies between the results of different models (in preparation).

DE VRIES, I., (Editor), 1992: *Report of the NSTF Modelling Workshop*, Report DGW-92.045, Tidal Waters Division, Directorate-General for Public Works and Water Management, Ministry of Transport, Public Works and Water Management, The Netherlands, 40 pp.

DE VRIES, H., BRETON, M., DE MULDER, T., KRESTENITIS, Y., OZER, J., PROCTOR, R., RUDDICK, K., SALOMON, J.-C., and VOORRIPS, A., 1995: A comparison of 2D storm surge models applied to three shallow European seas, *Environmental Software*, **10**, 23–42.

HACKETT, B., and ROED, L.P., 1994: Numerical modeling of the Halten Bank area: a validation study. *Tellus*, **46A**, 113–133.

JAMART, B.M., and OZER, J., 1989: Some results and comments on the Tidal Flow Forum exercise. *Advances in Water Resources*, **12**, 211–220.

KHAIN, A.P., ROSENVELD, D., and SEDNEV, I., 1993: Coastal effects in the Eastern Mediterranean as seen from experiments using a cloud ensemble model with detailed description of warm and ice microphysical processes, *Atmospheric Research*, **30**, 295–319.

PEECK, H.H., PROCTOR, R., and BROCKMANN, C., 1983: Operational storm surge models for the

North Sea. *Continental Shelf Research*, **2**, 317–329.

RUDDICK, K.G., DELEERSNIJDER, E., LUYTEN, P.J., and OZER, J., 1995: Haline stratification in the Rhine-Meuse freshwater plume: a three-dimensional model sensitivity analysis. *Continental Shelf Research* (in press).

STEIN, U., and ALPERT, P., 1993: Factor separation in numerical simulations. *Journal of the Atmospheric Sciences*, **50**, 2107–2115.

VERBOOM, G.K., DE RONDE, J.G., and VAN DIJK, R.P., 1992: A fine grid tidal flow and storm surge model of the North Sea. *Continental Shelf Research*, **12**, 213–233.

WERNER, F.E., 1989: 2nd Tidal Flow Forum. *Advances in Water Resources*, **12**, 107–108.

WERNER, F.E., 1995: A field test case for tidally forced flows: a review of the Tidal Flow Forum. In: *Quantitative Skill Assessment for Coastal Ocean Models*, D.R.Lynch and A.M. Davies (Editors), American Geophysical Union, Washington, D.C. (in press).

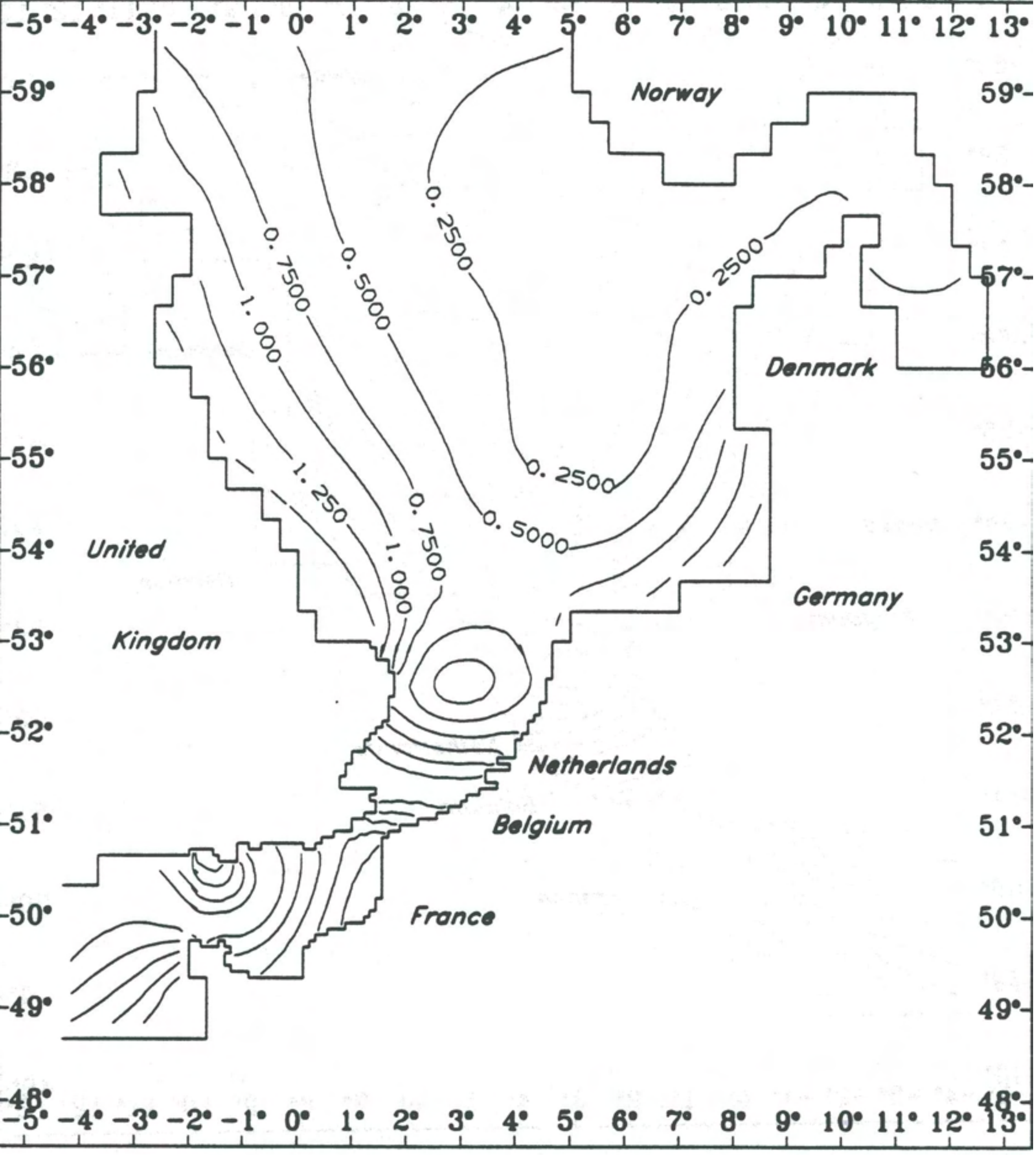

FIGURE 1
Deleersniider. Ozer and Tartinville

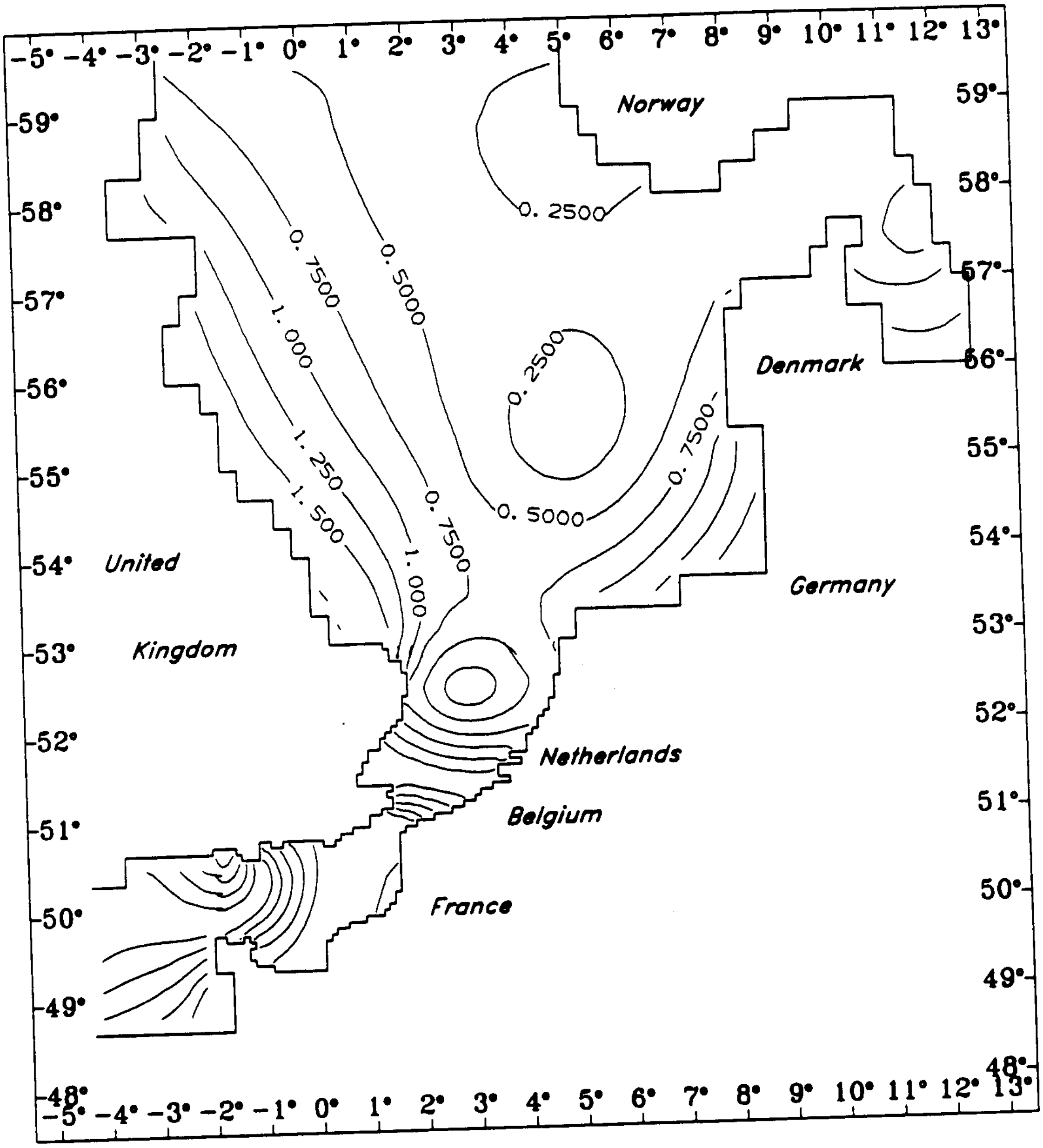

FIGURE 2
Deleersnijder, Ozer and Tartinville