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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ENVPREDRSCHFAC Technical Paper No. 3-75	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Summary Report of Hydrodynamical-Numerical (HN) Model Workshop and AGU Topical Meeting: Hydrodynamical-Numerical Models for Coastal and Open Ocean Areas		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) T. Laevastu		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Prediction Research Facility Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N/A
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command Department of the Navy Washington, D.C. 20361		12. REPORT DATE February 1975 13. NUMBER OF PAGES 93
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hydrodynamical-Numerical Models

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document summarizes the proceedings of the HN Model workshop and Americal Geophysical Union Topical meeting on HN Models held at Monterey, California in December 1974. A brief review is given of the history of HN models, the present state of the art and future needs. Problems with certain models, prescription of experiments, and priorities of future research are discussed and summary and recommendations from the AGU meeting are given. Abstracts of papers contributed at the AGU meeting are provided and the

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agendas and lists of participants at both the workshop and AGU meeting are given.

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AN  (1)   AD-A007 301
FG  (2)   080300
FG  (2)   200400
CI  (3)   (U)
CA  (5)   ENVIRONMENTAL PREDICTION RESEARCH FACILITY (NAVY)
          MONTEREY CALIF
TI  (6)   Hydrodynamical-Numerical (HN) Model Workshop and AGU
          Topical Meeting: Hydrodynamical-Numerical Models for
          Coastal and Open Ocean Areas Held at Monterey,
          California on 2-11 December 1974.
TC  (8)   (U)
DN  (9)   Summary rept.,
AU  (10)  Laevastu,T.
RD  (11)  Feb 1975
PG  (12)  95p
RS  (14)  ENVPREDRSCHF-tech paper-3-75
RC  (20)  Unclassified report
DE  (23)  *Ocean waves, *Coastal regions, *Hydrodynamics, *
          Meetings, Mathematical models, Tidal currents, Wind,
          Upwelling, Boundary layer, Shores, Continental shelves,
          Finite element analysis, Ocean models
DC  (24)  (U)
AB  (27)  The Hydrodynamical Numerical (HN) models are so far the
          only numerical models which have reproduced the real
          conditions and processes in the oceans satisfactorily.
          They have been applied in the past mainly for estuaries
          and semiclosed seas, but lately also for open coasts
          and open oceans, especially at the Environmental
          Prediction Research Facility (EPRF), in Monterey. The
          objective of the workshop was to review the present
          state of the art in the application of HN models,
          especially with respect to the slightly different
          numerical solutions used in different laboratories.
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ENVPREDRSCHFAC
Technical Paper No. 3-75

SUMMARY REPORT
OF
HYDRODYNAMICAL–NUMERICAL (HN) MODEL WORKSHOP
AND
AGU TOPICAL MEETING: HYDRODYNAMICAL–NUMERICAL MODELS FOR COASTAL AND OPEN OCEAN AREAS

HELD AT
MONTEREY, CALIFORNIA
2–11 DECEMBER 1974

FEBRUARY 1975

ENVIRONMENTAL PREDICTION RESEARCH FACILITY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940

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PART II - REPORT ON AGU TOPICAL MEETING

PART I
PROCEEDINGS OF THE HYDRODYNAMICAL-NUMERICAL (HN) MODEL WORKSHOP

I. GENERAL

1. BACKGROUND

The Hydrodynamical Numerical (HN) models are so far the only numerical models which have reproduced the real conditions and processes in the oceans satisfactorily. They have been applied in the past mainly for estuaries and semi-closed seas, but lately also for open coasts and open oceans, especially at the Environmental Prediction Research Facility (EPRF), in Monterey. The research on, and development of the HN model is proceeding in only a few institutions in the world. Considerable work is proceeding in northern Europe where these models are being adapted for routine analysis and forecasting, especially of storm surges and actual water depth for supertankers, and for coastal constructions of various kinds.

There are still some problems in extended application of the HN models where there are either several possible solutions or, as yet, no satisfactory solution at all. Various experiments and developments have continued independently in the few laboratories who are dealing with these models. Thus, there is a need to summarize and review these latest developments and make the results available for further use.

2. OBJECTIVES

The objectives of the workshop was to review the present state of the art in the application of the HN models, especially with respect to the slightly different numerical solutions used in different laboratories. Furthermore, it was found necessary to review and compare various new multi-layer and multi-level models and to decide on the best approaches to be followed in this subject. The second objective was to review the various past applications of HN models to a variety of practical problems and follow the success and problems in this matter. The main objective of the workshop was, however, to discuss the various approaches where the solution at hand is not necessarily a fully satisfactory one. These approaches were:

(a) Compare finite difference versus finite element methods.

(b) Compare multi-level and multi-layer models.

(c) Compare various diffusion and dispersion formalations.

(d) Compare various treatments of open boundaries.

(e) Determine the need for the inclusion of convective terms.

(f) Compare the approaches used for internal friction and horizontal viscosity.

(g) Compare the method and discuss the difficulties in obtaining satisfactory meteorological input data.

(h) Discuss the treatment of the vanishing layers.

(i) Discuss the problems connected with coupled oceanic-atmospheric models.

(j) Explore, further, the use of the method of "Wirkungspunkte".

(k) Find ways to incorporate small mesh grids inside larger ones.

(l) Discuss and find ways to obtain data for model verification and for input along open boundaries.

(m) Discuss the use of the models for designing field observations.

Among other problems subject to discussion were the preparation of a manual on HN models and possible international action in the application of HN models, as well as the possibilities for further experimentation and development of the models on an international basis.

3. ORGANIZATION

The workshop was sponsored by a small grant from Office of Naval Research (ONR), Codes 460 and 480. The convener of the workshop was Professor Walter Hansen, from the University of Hamburg, Germany. He was also the general chairman of the meeting. The agenda and list of participants are given as Appendixes A and B for Part I.

The workshop took place at the Environmental Prediction Research Facility in Monterey, from 2 through 7 December 1974.

II. INTRODUCTORY DISCUSSIONS

The workshop was opened by Captain R.C. Sherar, USN, Commanding Officer of EPRF. In the opening discussion, the agenda was amended and, for each item, a discussion leader and recorder was elected. It was decided that a brief report be given on each discussion. The detailed presentations of the results of recent works will occur within the "HN Method Digest" and the HN Models Manual, which was discussed as the last agenda item.

The discussions were very informal. As a result, participants openly described various experiments they had been conducting, even those in which the results had not been fully satisfactory, as well as various empirical approaches used to obtain, for example, open boundary conditions which can or have not been defended fully with theoretical considerations. As a result of these very open and frank discussions, considerable progress was made, especially in two directions: (1) to avoid unnecessary duplications in the future, taking into consideration past experiences and experiments by various scientists experimenting with HN models; and (2) by directing future research. To this end a number of recommendations were passed which are reproduced at the end of this report as Appendix B of Part II.

T. Laevastu

III. REVIEW OF PAST HISTORY AND PRESENT STATE OF THE ART OF THE HN MODELS

1. THE BASIC MODEL (incl. definition of HN and related models, finite difference forms, grid, etc.).

Professor Walter Hansen gave a review description of his model. His HN models are using a staggered grid with water heights computed at z points and u and v velocity components computed one half grid size to the right and below each corresponding z point. Land boundaries pass through u and v points, open boundaries through z points.

For boundary conditions the models have the velocity component normal to the land boundary equal to zero and the water heights are specified at the open boundary.

Often a need arises to link large and small grids, but there are problems here to correctly specifying the matching boundary condition.

There are also problems in choosing the proper grid size. One must be careful not to block openings. In one model of the North Sea, the English Channel was approximated with a boundary configuration that caused the flow to be abnormally low.

Dr. Laevastu reported that EPRF has managed the one cell, wide river problem with difficulty, but successfully, using special patches on the $\bar{z}$, $\bar{u}$ and $\bar{v}$ type computation. The step nature of the grid can also make land boundaries longer in the model than they are in nature. Hendershots, at Scripps, has tried to solve the coastline problem by approximating it with curves, but his method did not prove to be any better.

Professor Hansen reported further on the 37 km North Sea Model, the 4° world wide HN model, and ongoing work on a 9 km North Sea Model and a 1° world wide model.

Dr. Heaps presented the general features of his model. The grid uses the arrangement whereby the u and v components are computed on the sides of a grid cell and z is computed at the center of the cell, all at the same time instant. Land (closed) boundaries pass through u and v points. Open boundaries may be prescribed by water elevation at z points.

In these models the friction term may be a source of instability. Some effort has been made to eliminate the disturbing effect of term in shallow water areas by reformulation of the equations.

The large area British model surrounding the entire British Isles is in polar coordinates. This model uses tidal measurements from stations established at the edge of the continental shelf. These measurements are not yet complete. The tide measurements are generally of 1 to 1 1/2 months in duration and may have "drift" problems. German co-tidal charts, about 30 years old, have been shown to be inaccurate.

Other British models include 2-D models of the North Sea, a 1-D model of the Thames estuary connected to the North Sea model, and an Irish Sea model. A primary problem concerns open-boundary radiation conditions. In a comparison of two 1-D schemes in the Bristol Channel, an implicit and an explicit scheme both used the same time step to give comparable accuracy.

Dr. Schmitz presented his model scheme. His models use a staggered grid, but computed both u and v at positions 1/2 grid space below and 1/2 grid to the right of the z points on the edge of the z cells (same as Hansen's model). In Schmitz' model, α (a horizontal viscosity term) is used. By introducing α into the equation, the equations are no longer linear, so the Courant, Friedrich, Lewis stability criterion applies only approximately.

Dr. Liu presented the explicit scheme used in the 3-D models of the Rand Corporation. U and v are computed 1/2 grid step to the right and 1/2 grid step below z respectively. H, P, and T are also defined at the z point. His model is being used with a grid of 2400 points, a 500 ft grid and a 1-minute time step in the Chesapeake Bay.

Dr. Liu emphasized the need for correct boundary input data. For boundaries he only uses measured data, never "cosine" tides, because the "cosine" tide curve does not contain the high frequency energy (in shallow water). The model is being adjusted with cross-spectral analysis.

Dr. Crean presented the Strait of Georgia-Juan de Fuca model which uses the same grid described by Dr. Heaps. He followed the development of the present model from a simple 1-D model to the present 2-D model, which is linked to many 1-D models of the various channels and inlets in the model area. The 2-D model has a 4 km grid which still has problems in the island passages northwest of the Puget Sound inlet. This modeling effort is combined with intensive field work and has evolved slowly to the point where there is good agreement between the model results and the observations.

R. Bauer

2. DRIVING FORCES; OPEN BOUNDARIES AND THEIR TREATMENT

Eng. Duun-Christensen described the use of the Hansen-type HN model for the prediction of storm surges in the North Sea and Skagerrak-Kattegatt with emphasis on the input of winds. He used a 150 km grid for surface pressure analysis/forecasting, from which he computed the geostrophic wind. The geostrophic wind was converted to true surface wind with a curvilinear relation, using sea-air temperature difference as a stability factor. The linear geostrophic-surface wind relation of Hasse was found less satisfactory. His paper will be reproduced as one of the contributions to the "HN Method Digest".

Dr. Laevastu described the treatment of open boundaries at EPRF. Of special interest was the input of a "permanent" (thermohaline) current by describing a slope to open boundaries. The slope is computed either from Bernolli's theorem or from Margules' equation. At present, work is in progress to compute the geostrophic current component ("permanent current") from Robinson-Bauer, one-degree-square monthly mean temperature/salinity profiles (unpublished data). Laevastu further described the input of river flow and the computation of open boundaries by "depth restriction." He also described the treatment of three ("along the coast") and four (open ocean) open boundaries and showed some results from Southern California and Puerto Rico areas. Finally, he described briefly values from one section to another. In the case of semiclosed or closed sections (e.g. bays) there is a need to reproduce the volume of the water as an appendix to the entrance section.

Mr. Callaway described a three-open-boundaries model off the Oregon coast, where the boundary input was obtained from measurements of currents and tides at the open boundaries. He also discussed measurements taken at two points in New York Bight and emphasized the danger of relying on shore station tidal data alone.

Dr. Crean pointed out that the friction through channels and inlets and the corresponding proper presentation of these in the model is a principal determining factor.

T. Laevastu

3. VERIFICATION OF RESULTS: SEA LEVEL AND CURRENTS

Dr. Crean described his work with a numerical model of the waters to the South and East of Vancouver Island; the Strait of Juan de Fuca and Georgia Strait. Although an extensive field program had been carried out, tide gauge records have not been sufficient to yield the correct velocity field. Current meter observations indicated very high and questionable incoming transport apparently due to difficulties of evaluating transport with current records. The results of the full 2-dimensional model gave tide heights that agreed in amplitude and phase with observations at both ends of Vancouver Island. The model, in fact, reproduced the small scale features of the observed tide records.

It was found that the convective terms were required in the model due to the abrupt change in direction of the channel at the southern tip of Vancouver Island.

Dr. Sündermann presented a comparison of currents observed in hydraulic models and those computed by numerical models for the same geometry as the hydraulic model. The comparison consisted of photographs of currents in the hydraulic model, where the streamlines and eddies were made visible with floating particles, and computation of currents with the HN model. The agreement was good and convective terms were found to be important only in areas where the flow is sharply curved, such as at corners of the basin. The finite element method was also compared to the finite difference method. It was found that the finite element approach did not provide greater accuracy, nor greater resolution in the areas of interest, and required a greater time for setting up than the finite difference method. The computer time requirement for the finite element model was slightly higher than for the finite difference model.

S. Larson

4. ADJUSTMENT AND VERIFICATION OF MODELS BY USE OF CROSS-SPECTRAL ANALYSIS

Presently, numerical models are generally adjusted and verified by comparing observed tidal curves with the tides obtained by computation. It is also possible to compare the amplitude and phase relations for different tidal components between points of observations obtained at tide level stations in the prototype and in the model. Then the propagation and amplification of these tidal components in the model can be compared very accurately with those in the prototype. By means of this information, the flow resistance can be adjusted by changing the resistance parameters in the model if the agreement is not satisfactory.

For the amplitude and phase relations between the values of observation, cross-spectral analysis can be used. Cross-spectral analysis gives optimal estimates of these relations if the observations are perturbed by meteorological disturbances.

J.J. Leendertse

5. MULTI-LAYER AND MULTI-LEVEL MODELS

Multi-layer models have fixed grids and the surface and the internal boundary (ies) are vertically moveable, i.e., the thickness of the layers varies in space and time. The layers are usually vertically integrated. In multi-level models with a fixed grid net, only the surface elevation varies; however currents are computed at fixed, predetermined levels.

Dr. Schmitz presented results of computations of a schematical two-layer North Sea model and a two-layer model of the Arabian Sea. The second model including monsoon winds shows upwelling and downwelling phenomena. Dr. Laevastu pointed out some important practical consequences of these phenomena. Dr. Heaps asked for a comparison with a one layer schematic model for the North Sea. However, it has not been done as yet. Dr. Laevastu pointed out the advantages of multi-layer models, as compared to multi-level models. Dr. Voogt pointed out that for some kinds of estuary problems, multi-level models are also useful.

Dr. Heaps showed the possibility of resolving the vertical velocity distribution by analytic methods. Similar to the description of internal modes the velocities are represented by eigenfunctions and corresponding eigenvalues. Dr. Hansen pointed out another possibility of getting information about the vertical velocity distribution in two-dimensional models.

Dr. Liu gave remarks concerning the shear stresses for multi-layer models and the related question of energy conservation in modeling schemes. He presented the first results of an integrated numerical modeling system for one, two, and three dimensions.

Dr. Engel gave some preliminary results of a two-layer model for the North Sea.

M. Engel

6. THE METHOD OF "WIRKUNGSPUNKTE"

Professor Hansen reviewed the recent work with the method of "Wirkungspunkte" in HN models. He emphasized that when planning the placement of measuring and recording instruments, one may try a heuristic way to investigate cross correlation functions by calculating the effect of any disturbance in any place of special interest. Some examples are:

1. The storm surge in 1967 in Hamburg became disastrous, partly because an external surge entered the North Sea near Scotland which was not taken into account by prediction authorities. Systematic investigations with HN models gave the result that, for the German Bight, only disturbances very near the Scotish coast are relevant. Disturbances in midsea positions have little effect on any point of the North Sea,

while a disturbance near the Norwegian coast will yield some effect in the Skagerrak and Kattegatt.

2. In the North Atlantic Ocean, many properties of the circulation can be obtained by computing the effect of a Tradewind in only 4 points between the Azores and Cape Verde area, using a 4° model of the ocean.

3. Omitting tidal forces, the prescription of the measured tidal elevations in only one point of the 4° World Ocean model near Hawaii causes an oscillation which is surprisingly similar to the tidal oscillation, calculated from models of the entire World oceans. It was emphasized by Professor Hansen that often the points of maximum influence are not identical to those of maximum disturbance.

E. Maier-Reimer

7. WAVE DEFORMATION DURING COMPUTATION AND ITS PREDICTION

In a mathematical model, wave propagation is usually different from wave propagation in nature. Dr. Leendertse discussed the concept of the wave amplification. The propagation of a progressing wave is computed and the amplification of its amplitude and the change in its phase are also computed depending on the number of grid points per wave length. The amplitude generally amplifies while the phases show a lag.

The phase lag is most severe in the case of an area with two open boundaries opposite each other when a limited number of grid points are used. Then the wave speed is too low and the area seems to be elongated. Consequently, the computed velocities in the mathematical models are generally too low. The behavior of the model can be studied by applying the cross-spectral method to the model results. Amplification and phase lag are easily determined. The same procedure can be used for the observed values.

Dr. Oliger gave an overview of the possibilities of the use of higher-order systems. A recent comparison suggested the use of a 4th order scheme. The additional boundary value problems can be met by using a smaller grid size near the boundary where a second-order approximation is allowed. An objection to higher-order methods was raised as follows: if more computer time will be used, it is better to apply the second-order method and to reduce the grid size. Then a more accurate bottom schematization can be obtained.

J. Voogt

IV. REVIEW OF PAST APPLICATIONS AND FUTURE NEEDS

1. STORM SURGES, SEA LEVEL AND DEPTH PREDICTIONS

The discussion emphasized both the importance of hindcasting experiments and the development of real time forecasting systems. For the latter purpose, the cooperation of meteorologists was recognized as being of vital importance -- namely to ensure that HN models could be supplied with satisfactory meteorological data. It was suggested that atmospheric models of smaller grid scale should be developed to facilitate the prediction of the meteorological field over the sea surface in more detail, including the reproduction of fronts and the associated winds.

The following recommendations arose from the discussion:

(1) In the numerical prediction of storm surges a close working cooperation between oceanographers and meteorologists should be considered necessary; the meteorologists should be encouraged to develop atmospheric models of smaller grid size.

(2) The hindcasting of major storm surges using HN models with past data should be regarded as essential to throw light on the future prediction of such major and of rare events.

(3) There should be centers for national and international cooperation in the forecasting of storm surges, linked to weather forecasting centers. This particularly applies to the North Sea.

Mr. Duun-Christensen described his hindcasting experiments with an HN model of the North Sea, covering the periods 22-25 February and 15-18 October, 1967. He demonstrated results showing comparisons between observed and computed values of both total and residual sea levels, at various points around the shores of the North Sea. For each period considered, an estimation of errors was carried out showing considerable scatter. Concerning open boundary conditions, there was no external surge, only a statical pressure rise and ten tidal constituents being prescribed.

The relative merits of (a) deterministic, (b) statistical, and (c) state-estimation models was discussed. In (b), the value of cross-correlations was emphasized by Dr. Leendertse. Type (c) contains elements of both (a) and (b) and therefore, appears to offer the best hope for a reliable predictive tool.

N. Heaps

2. EFFECTS ON COASTAL CONSTRUCTION

Dr. Voogt presented a review of the application of HN models in Holland for the design of various coastal constructions and especially with respect to damming the Zuidersee and various Dutch inlets. The open boundaries for these models are obtained from carefully designed measurements by a multitude of ships. In addition, empirical transfer functions are used to obtain boundary values from internal recording points.

Professor Hensen presented a review of the application of HN models for the design of a deep sea port off the German coast and the possible effect of the dam at this port on the storm surges and tides in the vicinity.

Dr. Laevastu described a few applications of the HN model at EPRF for obtaining currents for pier constructions in San Diego Bay and obtaining current data for supertanker mooring sites.

The following discussions emphasized the need to propagate the knowledge of the use of HN models to coastal engineers.

T. Laevastu

3. CURRENTS AND POLLUTANTS

R.J. Callaway spoke of a current U.S. Environmental Protection Agency program in the New York Bight. Using hydrodynamical-numerical models as an integral part of this multi-disciplinary program, the effects and dissipation of sewage sludge at an experimental dumping site are to be studied.

N.S. Heaps described his three dimensional HN model of the Irish Sea and its verification using submerged telephone cables to measure net flow via electric potential in the cables.

Cesium 137 is disharged into the Southern North Sea by the Cherbourg nuclear plant. E. Maier-Reimer reported that measured concentrations of this isotope transported in coastal waters to the German Bight area are in qualitative agreement with those predicted by an HN model using average North Sea wind conditions.

Speaking to the future needs part of this section, Dr. Laevastu stressed the need for HN model verification, perhaps best accomplished where extensive data coverage is already available. This initiated several comments, including suggested areas by N.S. Heaps, (Lake Ontario), R. J. Callaway, (C.U.E. area off Oregon), and P.B. Crean, (Strait of Juan de Fuca). W. Hansen suggested a recommendation for verification exercises covering several areas where data coverage is available and possibly where major survey programs are to be conducted in the next ten years. R.J. Callaway suggested an addition to this recommendation with respect to the future use of HN models in pollution problems.

Referencing the first of these recommendations, J. Leendertse stressed that the models are not so simply transferred and that to convince people of a predictive capability, an HN model must be specifically tuned to that area.

W. Hansen agreed that first the models must be tested where measure of data are required. The second step is forecasting.

Two preliminary recommendations arose from this discussion:

(1) It is recommended that, for testing purposes, HN models be applied to various geographical areas where extensive oceanographic and meteorological data coverage is available. These areas might include the Strait of Juan de Fuca, Lake Ontario, and the Coastal Upwelling Experiment study area off the Oregon coast.

(2) It is recommended that HN models be further developed with regard to their utility in pollution problems. In particular, small grid scale models should be examined as to their application in ecological simulations.

J. Harding

4. MATHEMATICAL MODELS OF TURBULENCE

Dr. Sundermann discussed the relevance of Spalding's[1] so-called two-equation deterministic model of turbulence for coastal investigations. This model is based on the Navier-Stokes equations (including the Boussinesq approximation) and the following modeling of the turbulent eddy viscosity coefficient A:

$$A = g\sqrt{kl}$$

$$k = 1/2\ \overline{v_i' \ u_i'}$$ - energy of turbulent fluctuations

l = characteristic length scale of turbulence ("mixing length")

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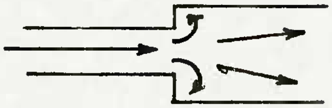
[1] B.E. Launder and D.B. Spalding, 1972: "Mathematical Models of Turbulence", New York, Academic Press

The two quantities k and l are obtained by two corresponding transport equations which must be solved together with the equations of motion and the continuity equation. An obvious advantage is that there is no arbitrary choice of A (e.g. as a constant), but an approach close to the underlying physics.

This field is still not investigated in coastal oceanography. A first application has been started for a horizontal flow in an abruptly widened channel.



Mr. R. J. Callaway gave some remarks on subsurface horizontal dispersion of pollutants in open coastal waters, and on the determination of horizontal diffusion coefficients (depending on the depth) by means of data collected during the Coastal Upwelling Experiment (CUE-1).

$$E = v^1 \bar{u} \, \beta \int_0^\infty R_{\underline{F}} \; (T) \; dt$$

v^1	turbulent eddy velocity
$\bar{u}$	mean velocity
β	ratio of the Lagrangian to Eulerian integral time scales
$R_{\underline{F}}$	(T) Eulerian correlation coefficient

Results: Typical values of the order of magnitude of 10^5 cm^2/sec, mostly decreasing slightly with depth. Depth levels 20, 40, 60, 80, 120 meters. The 1 $^{3/4}$ hypothesis is not well fitted by the data.

J. Sündermann

5. NET CIRCULATION PREDICTIONS

Dr. Heaps introduced the session by emphasizing the importance of a proper definition of time scale in net circulation problems. Thus, whether the phenomena being studied is taken over one tidal cycle or over several months or years should be clearly stated. He also indicated the variability in net circulation which could be encountered in such places as the northern North Sea, in which case long-term averages were often unhelpful in reaching conclusions concerning net flow characteristics.

Professor Hansen suggested the use of HN models in the simulation of net currents, considering periods for which the relevant conditions of wind, tide and density distribution were known.

Dr. Matthews described various problems encountered in fjord circulation including the seven-year cycle of bottom water replacement in some Alaskan fjords. It appears that this cycle is largely determined by water conditions outside the fjord.

The use of drogues and bottom drifters for the measurement of net circulation was discussed with particular reference to an area off the West African coast and to the Irish Sea. The measurements of this kind constitute one way in which the results of current circulation derived from HN models can be verified observationally.

Dr. Sündermann spoke about the net circulation (over a tidal M_2 cycle) in the southern North Sea, describing results from an HN tidal model of the area which demonstrated a distinctive drift from west to east over much of the region. Non-linear frictional terms were responsible for this.

N. Heaps

6. DESIGN OF ENGINEERING COMPUTATION SYSTEM

For engineering applications of numerical models it is required that the boundary and input conditions of a model can be changed easily and that a complete documentation is available of inputs and outputs of model experiments. This documentation should be easily accessible and the outputs should be available as graphs and charts to make a direct comparison possible between experimental results and prototype data as well as comparisons between results of different experiments.

Dr. Leedertse presented an overview of the capabilities of such a system and the different steps which are required in its use.

J. Leendertse

7. THE APPLICATION OF THE METHOD OF "WIRKUNGSPUNKTE"

Professor Hansen described in detail four different experiments which led to the discovery and application of the method of "Wirkungspunkte" in the University of Hamburg. The first approach was applied to the North Sea where a disturbance was described at four different locations on the open boundary and the propagation of the disturbance from these points was followed in time. The results confirmed the earlier empirical knowledge that the disturbance along the Scottish coast moved down along the British coast into the German Bight, whereas, the disturbance form other points did not influence the German Bight at all. On the other hand, the disturbance near the Norwegian coast moved into the Skagerrak and Kattegatt.

The second application was by describing a disturbance with random variations across the full input boundary. The results showed that most of the disturbance was filtered out throughout the propagation with exception of those modes which coincide closely with the Eigenschwingunen resonant periods of the North Sea.

The third application was for the North Atlantic where wind was described at 4 grid points between the Azores and Cape Verde Islands. The result was the development of a current similar to the North Equatorial current and the Gulf Stream, as well as a gyre in the Sargasso Sea.

The fourth application was with the world ocean tides where tides were described only at one point in the Hawaiian Islands. After a period of computation, the world tides similar to empirically estimated tides, developed in all oceans.

In the following discussion, the great utility of this method for various investigations was emphasized. It was pointed out that this method can be used to investigate the areas which are in rest and which are in unrest in the ocean. Furthermore, this method can be used for the design of field observations and the designation of recording sites for measurements in the areas of unrest from which the disturbances propagate. Finally, it was recommended that this method be applied to investigate the effect of small changes in wind fields on the current system in the oceans which might reveal many aspects of the climatic changes in connection with oceanic changes.

T. Laevastu

8. SEDIMENT TRANSPORT

Dr. Sundermann explained that the problem of the quantitive treatment of sediment transport in a coastal region is extremely important from a practical point of view. An appropriate numerical model could save an enormous amount of money for dredging. This work is only just beginning. The main difficulties are:

1. The problem is essentially 3-dimensional.
2. Very little is known on the mechanics of sediment transport.

3. There is an interaction between the dynamics of the water and the sediment transport.

Nevertheless, a first very simple approach for the large scale sand movement due to tides has been carried out for the North Sea. It is based on the following relationship between the transported sand mass q and the motion field developed by several authors:

$$q = q\ (v_1\ ,\ v_1\ (\mathrm{crit}))$$

where v_1 is the velocity vector, v_1 (crit) a critical velocity (depending on the grain size) for the beginning of the transport. Using the Bagnold formula, a mean transport field is calculated for the tide in the North Sea. The main features of this field are in a certain agreement with the observed pattern given by A.H. Stride.

In discussion it was pointed out that this field of investigation is extremely difficult and a solution of the problem is not yet mastered. In addition, in the nearshore region, the transport by the surface waves is of great importance. This might be introduced into the model by an appropriate parameterization. The investigation of the sediment transport requires a very close cooperation of different disciplines, especially of mathematical and physical modelers. The numerical way seems, in the long run, the only hope to beat this problem quantitatively and to have a tool for prediction. Therefore, the work should be reinforced.

J. Sündermann

V. INTERNATIONAL COOPERATION

In general discussion, the insufficiency of single national needs and funds for synoptic ocean analysis and prediction was pointed out. Furthermore, there is a lack of service organizations in oceanography in the world. However, new needs for synoptic computations of various parameters and processes in the oceans, which must be considered international, are arising. For example, the new supertankers require synoptic predictions of water depth in relatively shallow passages, such as the Danish sounds and the English Channel. Many pollution problems require the prediction of the movement and fate of the pollutants in the ocean. There is an urgent need to investigate the effect of the ocean on the weather and vice versa, including the oceanic water cycle.

It was decided that international collaboration in the preparation and use of applicable numerical models for the solving of pressing oceanographic problems should be intensified. Among the actions needed was to find a few centers in the world where work on Hydrodynamical-Numerical models could be carried out and where experiences and knowledge could be exchanged. These centers should have computer facilities as well as easy access to other environmental data (especially meteorological data).

It was decided to recommend to IAPSO that a working group should be formed on Hydrodynamical-Numerical models which could be a forum for scientific collaboration in this matter. Furthermore, it was suggested that the knowledge of the availability and performance of HN models be passed to coastal engineers and others who might make use of them.

Professor Hansen reviewed the present situation with the numerical modeling and prediction in Germany, emphasizing that only in cases of great need do people come to his institution and fund the projects. Meanwhile, no continuous funding or interest exists. The same situation is apparent in the inter-European collaboration with respect to the North Sea and the Baltic. Dr. Laevastu reviewed the situation in the USA, emphasizing that the interest in oceanic services has decreased because there is no spokesman for maritime interest in the U.S. Senate or House of Representatives and that there are only very small fragmented efforts in various Federal agencies. However, an attempt is being made, mainly through the initiative of EPRF, to coordinate the Federal action in oceanic analysis and prediction. In addition, the need for close collaboration with meteorological service centers was emphasized. It was also emphasized that collaboration with the empirical oceanographers must be intensified.

Some discussion centered about the possibility of continuing the national effort under the auspices of NATO and UNESCO. With respect to the last organization, it was pointed out that the developing countries have also urgent needs for the application of HN models, but none have the expertise or the facilities. It was discussed, furthermore, that there might be a possibility to establish an international center along the lines of the European Center for Medium Range Weather Forecasting. Otherwise, other centers in the world could be designated where oceanographers could work together with meteorologists in numerical modeling and the verification of models. It was, furthermore, pointed out by Dr. Crean that in Canada the voice of the modelers is much better heard than in many other countries and that the recommendation to obtain bigger computer facilities rather than bigger new oceanographic research ships has been heard. Two recommendations were prepared under this agenda item.

T. Laevastu

VI. IDENTIFICATION OF EXISTING, NOT FULLY EXPLORED PROBLEMS WITH HN MODELS, PRESCRIPTION OF EXPERIMENTS AND PRIORITIES OF RESEARCH

1. COMPARISON OF FINITE DIFFERENCE AND FINITE ELEMENT METHOD

Dr. Sündermann gave a short introduction to the finite element method, presenting some results for the tides in a schematic estuary and for a coarse grid model of the North Sea.

His conclusions were that the question is not yet decided whether the finite difference technique is more suited to hydrodynamic problems than the finite element method. Obviously the computational requirement of the finite element method is much higher than that of the finite difference method. The conservation behavior of the finite element method is not sufficiently well known.

An advantage of the finite element method, is the high flexibility of the discretization. This leads to a very economic approximation of given natural geometrical or dynamical conditions.

A very accurate comparison of both methods is still missed. This should include the observed results, the behavior with respect to consistency, convergence, stability, and the computational effort needed.

Discussion: The need for such a comparison was underlined by several participants. Dr. Sündermann's work will be reproduced in the "HN Methods Digest".

J. Sündermann

2. COMPARISON OF VARIOUS TYPES OF MULTI-LAYER MODELS

The different types of multi-layer, as well as multi-level, models and their results were briefly presented by Hansen, Maier-Reimer, Schmitz, Heaps and Engel. Although plausible results are obtained with all the models, there is no direct detailed comparison of the results available nor the comparison of practical aspects of the models such as computer core and time requirements. Laevastu explained that there are, at EPRF, three slightly different multi-layer models originating mainly from Professor Hansen's institute. Some comparison of those models has been made in the Strait of Gibraltar and slight differences from model to model have been noticed. There are, also, considerable differences in computer running time. However, it has not been possible to make a strict comparison because the input-output routines in various models are also different.

In the discussion which followed it was suggested that an effort be made to compare the different basic formulations of the models and try to compare the multi-layer and multi-level models. It was, furthermore, decided that one area would be selected for comparison of the model results (i.e., an area where the input data as well as data for verification are available). It was suggested that only the basic model, rather than the input and output routines be compared. One recommendation originated from this discussion which was materially modified later during the open meeting.

Further difficulties with the multi-layer model input, such as the input of internal tides on the open boundary and the problems of vanishing layers, were discussed.

T. Laevastu

3. COMPARISON OF VARIOUS TREATMENTS OF MULTIPLE BOUNDARIES AND USE OF THE MODEL WITH FOUR OPEN BOUNDARIES FOR OPEN OCEAN AREAS

Dr. Oliger reviewed a paper by T. Elvins and Crist, to be published this year, on their work on boundary conditions for shallow water equations and pointed out that the inflow conditions require more information than the outflow. On the boundaries it is best to specify u and v, but these are the hardest to measure. Consequently, there is no real answer to what is best, unless related to a particular problem. By proper position of the grid the problems on the boundaries can be minimized, but this judgement takes experience. It is possible to freeze coefficients locally to overcome difficult problems.

Dr. Mungall presented the radiation boundary condition discussed in his paper presented at the open meeting. Dr. Hurlburt also presented a paper which was later presented at the open meeting.

Dr. Laevastu discussed some of the ways EPRF has handled the flow in bays by creating false basins for the end of the bay, which contain the volume which is excluded in the inlet section.

R. Bauer

4. DIFFUSION AND DISPERSION FORMULATION AND COMPARISON

Dr. Maier-Reimer presented results of an extensive study on different formulations of diffusion and dispersion computations. He found that the best approach for the problem was the so called Monte Carlo method. These methods will be described in the "HN Model Manual."

Mr. Harding presented the results from a conservative advection scheme which he has developed from a one-dimensional to a three-dimensional case. This method has been proposed by scientist from the Danish Meteorological Institute. It is being used in HN models as well as in other models in Monterey.

Dr. Laevastu pointed out that the simple diffusion scheme, which he has been using in the past, works satisfactorily in small scale models where the tidal excursion is at least 2 grid distances. It does not work satisfactorily in large scale models.

In discussions, the need to reproduce the results of large scale dye experiments, such as the RHENO experiment, was pointed out and a recommendation resulted from this discussion.

T. Laevastu

5. ASPECTS OF ENERGY TRANSFER FROM ONE FREQUENCY TO ANOTHER

Dr. Leendertse pointed out that the non-linear terms in the equations provide an energy transfer from one frequency to another. The effect of the advective terms will be found in the second higher harmonic, while the quadratic bottom friction term is primarily responsible for the third higher harmonic. The aim of the models is to properly represent this energy transfer.

J. Voogt

6. THE DETERMINATION OF THE NEED FOR INCLUSION OF CONVECTIVE TERMS IN SMALL-SCALE MODELS

Mr. Voogt showed a model of an area near the Dutch coast where a large circulation builds up during ebb tide (two or three kilometers diameter). It is only possible to simulate this eddy in the model when the advective terms are included. Dr. Sundermann described a similar experience. Dr. Crean mentioned a model with a large grid size ($\Delta X = 4$ km) which could also only reproduce eddies when including the advective terms.

It appeared that users of Leendertse's method, as well as Hansen's method, had the same experiences regarding non-linear instabilities with advective terms. The instabilities arose when the advective terms were important (in strongly curved streamlines). The instabilities could be suppressed by omitting those terms. It was recommended that the difference approximation of the advective terms was a badly needed research project. To study the performance of the different numerical models it was recommended that a difficult flow case should be computed by the different computational methods with the same input data (boundary values and depth schematization).

Dr. Hurlburt suggested that even in large-scale ocean models the advective terms should not be omitted.

J. Voogt

7. TREATMENT OF INTERNAL FRICTION AND HORIZONTAL VISCOSITY

The general discussions in this subject related to the use of the horizontal viscosity or the "smoothing factor," especially in the lower layers of multi-layer models, and the proper use of internal friction coefficient in the multi-layer models. It was concluded that further experimental work in numerical modeling in this subject must be carried out for areas where good measurements and verification data are available. Any direct measurements of these quantities (internal friction and horizontal viscosity) is, of course, impossible and the use of numerical values depends very much on the numerical formulation itself.

In discussions it was suggested that, in addition to bringing observational and numerical studies together, some applicable theoretical studies in this subject should be encouraged as well. Beyond setting initial and boundary values and determining verification fields, observations can serve to identify, characterize, and parameterize processes for the purposes of eddy coefficient determination, entrainment modeling, etc.

T. Laevastu

8. USE OF "FALSE BOTTOM"

Dr. Laevastu described the possibility and the practice at EPRF to describe a false bottom to deeper holes and to deeper areas or corners of a computational area if the area reaches over the continental shelf into deep ocean. This will result in a longer time step and considerable saving of computation time. However, the results over the deep water are, of course, uncertain and unrealistic. He pointed out, also, the possible pitfalls and short comings of this approach.

Another approach with the "false bottom" was related to wind current computations where the wind effect is computed from the surface to the top of the thermocline only, whereas, the tidal current reaches from surface to the bottom. Again, the advantages and disadvantages of this method were pointed out. The latter approach allows the consideration of a two-layered system with a vertically integrated model.

T. Laevastu

9. COMPARISON OF METHODS OF WIND STRESS AND OIL DISPERSION COMPUTATIONS

Concerning the motion in the oceans, near the shore, in adjacent seas, in bays, in estuaries, or in inlets, the incoming tide waves and the meteorological effects dominate. The effects of the wind cause many problems in the models because the dynamic air-sea interaction processes are scarcely known sufficiently and because the available fields of surface winds and pressure are not analyzed and predicted with the details and accuracy which are needed for useful forecasts of, for example, storm surges or of the distribution of mass and currents within the waters of bays and inlets.

The wind stress at the sea surface is usually calculated from

$$\Pi = \rho_{air} \quad C_D / \mathbb{V}_D - \mathbb{V}_S / (\mathbb{V}_D - \mathbb{V}_S) \qquad (1)$$

where C_D is the drag coefficient corresponding to that altitude D above the averaged water surface at which the mean wind speed $\mathbb{V}_D$ is prescribed; normally we have D = 10 meters. (1) may be derived from the semi-empirical theory of Prandtl concerning the vertical variation of wind speed in the Prandtl layer. In (1), $\mathbb{V}_s$ is the average velocity of the surface current. Because $\mathbb{V}_S$ is small compared with $\mathbb{V}_D$ in the case of storms and because $\mathbb{V}_D$ is seldom given accurately, $\mathbb{V}_S$ is scarcely taken into account although it may get some importance in the presence of strong tidal currents as in estuaries and channels.

The drag coefficient C_D does not only decrease with increasing altitude D but varies noticably, also, with the thermal stability within the Prandtl layer and with the roughness Z_o of the sea surface, and even with the amount of $\mathbb{V}_D$ (or $\mathbb{V}_D - \mathbb{V}_S$):

$$C_h = C_h \left(\frac{d\sigma}{dz}, Z_o, \mathbb{V}_D\right) \qquad (2)$$

Here the thermal stability is expressed by the vertical change of the potential temperature σ of the air. Especially Z_o will vary with sea and swell and partly with $\mathbb{V}_D - \mathbb{V}_s$ because wind waves at the surface become steeper if $\mathbb{V}_D$ and $\mathbb{V}_S$ possess an opposite component (Roll). Only in the case of neutral stability and omitting difference between the mean wind at the surface and $\mathbb{V}_s$ C_h and Z_o may be related to Prandtl's conception. Therefore, we may not wonder that there are slightly contrary opinions concerning the variation of C_D from nearly a constant (Brocks) to a noticeable increase with the mean wind speed (Charnock), and the amount of C_D seems to variate between $1.2 * 10^{-3}$ and $3.0 * 10^{-3}$ as used by Platzmann 1963 to simulate a Lake Erie storm surge.

But disregarding the employment of probably locally-affected near-shore wind observations in HN models there are weighty reasons for the use of a C_D larger than Brocks' $1.3 * 10^{-3}$ when applying manual and numerical weather analysis and prediction maps because these contain physical and numerical defects.

A full treatment of the wind stress by J.H. Schmitz will appear as a contribution to "HN Method Digest."

J.H. Schmitz

10. TREATMENT OF VANISHING LAYERS

The discussion of this item advanced into two areas. One covered the treatment of the moving boundaries in computations with a vertically integrated model over tidal flats which can run dry. Dr. Leendertse explained his approach in this matter, and Dr. Hansen showed some approaches he used in Hamburg, as well as in the computation of inundation in case of storm surges over dikes.

Some lengthy discussions centered around the problem of the treatment of the moving boundaries in multi-layer models. It was decided that this is essentially a time-consuming programming problem and great care should be taken in designing the computer program for this purpose. No help in this matter can be expected from meteorologists as this problem does not exist in meteorology in the same fashion.

T. Laevastu

11. COUPLING OF HN MODELS WITH TIDE GENERATING MODELS AND ATMOSPHERIC MODELS

Dr. Heaps presented a North Sea model including the continental shelf around the British Isles. This model was combined with a meteorological grid designed by the Meteorological Office in Bracknell. Values of air pressure from the 1000 mb level (near surface level) are accessible from magnetic tape for 36-hour forecasts, which are computed in the Meteorological Office every 12 hours. However, about the first 12 hours may be inaccurate and are not used in the model.

There have been, until now, only a few cases investigated (example shown from April 1973). Verification by comparison shows general agreement, but a remarkable negative surge has not been reproduced. The tide was not included in the model.

Dr. Sundermann discussed the importance of the input of tide, and mentioned that it might not be neglected in storm surge models. Mr. Duun-Christensen recommended comparison of computed winds with observed ones. Dr. Laevastu pointed out that it was difficult to receive reliable data from large mesh size numerical models of the atmosphere. Professor Hansen talked about the investigations of storm surges in the North Sea during 1973. The results were depending on the accuracy of the wind field. Dr. Leendertse pointed out that the model should be calibrated (bottom friction coefficient) with tide before introducing wind stresses. Dr. Laevastu described the application of L. Bengtsson's 3-parameter small grid atmospheric model in the Gulf of Alaska with a grid size of 40 nautical miles. The boundary values for this model are taken from a hemispheric model of the atmosphere. These atmospheric models are combined with a Hansen HN model, spectroangular wave model, and surf models.

Discussion on oil dispersion pointed out that there are many models, but none has been properly tested. Mr. Duun-Christensen pointed out, in answering Dr. Leendertse, that one should be careful with the calibration of storm surge models with the undisturbed tide, as there is a noticeable difference between the tidal currents and wind driven currents (Sundermann's 3-D Model) and the bottom friction may have a different influence in these cases. Furthermore, Mr. Duun-Christensen presented a Danish North Sea model combined with meteorological grid (which has a grid size 4 times the grid distance of the oceanographic grid).

J. Duun-Christensen

Dr. Schmitz gave the following recommendations concerning wind stress computations and the coupling of HN models to atmospheric prediction models:

(1) The numerical analysis of atmospheric sea surface quantities should be prepared in a rather small grid with point distances 40 to 100 km in order to be able to take into account the effect of (a) fronts, especially jumps in the direction of the wind, squall lines and temporary gusts, and (b) in the computation of stress and other quantities for the surface of the HN model.

(2) Regarding the considerable smoothing effects of necessarily balancing the initial fields of wind and pressure to suppress gravity waves in the usual baroclinic prediction models, there should be provided an advection forecast model for the sea surface working the same narrow grid as the forementioned analysis in order to cover the first 12 to 18 hours, after the time of the observations which supply the initial fields of the baroclinic atmospheric prediction model.

(3) The usual baroclinic forecast for the surface of sea areas covered by HN prediction models should proceed in a grid with point distances less than 100 km in order to

provide the necessary details for that time of prediction, $\geqq$ 18 h, which follows up the advection model. The transition from the advective to the baroclinic prediction may be provided by interpolation.

(4) The forementioned analysis and predictions should also be available near the top of the Pradtl layer (10 to 20 meters above the surface) in order to be able to consider the frequently essential effects of stratification in the atmosphere to the air-sea interaction process and in order to provide a wind speed directly for the altitude of about 10 meters above the sea surface. Doing this avoids the computation of surface winds from the field of surface pressure which is required at present if the wind of the 900 mb level being computed in baroclinic models is not applied.

J. H. Schmitz

12. EFFECT OF COARSENESS OF THE NET ON THE RESULTS, AND NESTED GRIDS

The introduction of grid refinement usually derives from the need for detailed resolution of the computed fields in model regions of particular interest. In the course of these discussions, references to the role of convective acceleration clearly emphasized the need for a detailed representation of the velocity field in the vicinity of important topographical features. It may also be desirable to locate computation points coincident with points where observations have been made or results are required. The primary problem in grid refinement relates to numerical reflection and dispersion of waves that may arise at points where a mesh of one size meets one of a different size.

It is, however, desirable to consider at this point some of the alternative approaches to joining grids of different sizes. These include:

(1) Different coordinate systems such as, for example, the application of a polar coordinate system in the modeling of the English Channel.

(2) The use of orthogonal coordinates as applied, for example, to the Bay of Fundy, or by Texas A & M to describe the progress of a hurricane from deep to shallow water, one of the coordinate lines being required to coincide closely with the coast. The associated transformation involves the use of travel-time coordinates as determined by the transformation:

$$\Theta = \int_{x}^{x_z} \frac{\partial x}{\sqrt{gh}}$$

Grid lines in one dimension can be made to conform approximately to the Courant, Friedrichs, Lewy condition.

(3) The use of finite element techniques such as discussed already by Dr. Sündermann.

(4) The extension of the 3rd implicit method due to Dronkers from one-to two-dimensional applications. The method is based on an ADI technique and permits variations in the spacing of horizontal and vertical grid lines. (Mungall) Trail applications were made to a "rectangular" North Sea and Cook Inlet. In the case of the North Sea, detailed grid resolution was applied near amphidromic points. The agreement between observed results obtained with constant grid spacing and results obtained with the unequal grid spacing for the M_2 tide was excellent. No reflection of the wave due to unequal grid spacing was noticeable.

A further trial application with unequal grid spacing was made to the propagation of the M_2 tide in Cook Inlet. The longest discrepancy encountered involved a phase error of 10° between the observed and computed values at the head of the inlet (in a 140° phase difference over the length of the inlet).

Dr. Heaps described the application of a model formulated by D.A. Greenberg involving different grid sizes in the Bay of Fundy. The first (and most coarse) grid extended from the edge of the continental shelf to the entrance of the Bay of Fundy. The second, smaller grid size was applied to the Bay of Fundy itself. The last and finest grid size was applied to Minas Basin, the location of a proposed installation for the generation of tidal power. The essential physical feature of the problem is that the tidal co-oscillation in the Bay of Fundy is near to resonance. The introduction of barriers could significantly increase or decrease the amplification of the tide in the system. The very large tides currently existing might, in fact, be much diminished.

A good deal of previous work on this system had involved models of the Bay of Fundy in which, for reasons of economy, origining with the use of a constant grid size, the open boundaries of the model did not extend out to sea sufficiently for adequate modeling of resonance effects. It is now understood that the resonance area extends at least to the edge of the continental shelf.

In the areas of the joints there is usually a set of missing points which must be supplied by geometric interpolation. An essential requirement is the maintenance of continuity through the juction. The agreement between the observed and computed values of the tidal constants was good. Of particular interest were the modifications of the tidal regime deriving from the introduction of barriers. These modifications were unlike those revealed by the more elementary models.

Dr. Hurlburt called attention to the early work of Dr. Kirk Bryan, who discussed the adjustments required at grid junctions to avoid loss of energy or mass. Further, he mentioned the single layer modeling of the Great Lakes. The lakes were mapped on a rectangular grid system using empirical coordinate transformations. The rectangular grid was so arranged at to give detailed representation of areas of particular dynamic interest. The application of such a technique to the Minas Basin would still involve a very large number of grid points.

Dr. Hurlburt stated that he regularly uses a variable grid, but in the sense of that used by Mungall. He described a simple zonal, coupled oceanographic and atmospheric model in which a synoptic north wind imparted momentum to the sea and the sea determined the heat flow to the atmosphere.

Dr. Mungall stated that, in connection with the one and two-dimensional schemes, reference should be made to Dr. Crean. In particular, it is recommended that when rivers or similar hydraulic features connect with the two-dimensional model, efforts should be made to add on a one-dimensional model rather than to attempt to specify a precomputed tide height or flow. In this matter, an improvement in the computed results of the model will usually be found.

Dr. Laevastu referred to the nesting of grids as employed by meteorologists but considered its application to oceanographic problems difficult. One can telescope from a coarse to a small grid easily, but not from a small to a coarse one.

Dr. Hurlburt referred to the work of Rao and of Mathur who used a variable fine grid embedded in a coarse grid to simulate the motion of a hurricane.

Dr. Sundermann showed a scheme of mesh refinement applied in the North Sea. The grid junction lay along a diagonal line of elevation points and afforded a more detailed resolution of the German Bight.

P.B. Crean

13. VERIFICATION (AND DATA) NEEDS AND NEED FOR PRE-EXPERIMENTAL MODEL RUNS

In general discussion it was pointed out that there is a great need for good observations (recordings) on currents and sea level for verification purposes, as well as for boundary input for areas and times where HN models are or have been run. Especially, current recordings are, in most cases, missing. The verification data are important in showing and demonstrating to potential users, as well as to empirical descriptive oceanographers, how well the models can reproduce the conditions and processes in the sea. It was decided that efforts be made to explain the specific data needs to the oceanographers who are making the measurements, and emphasize especially that the measurements at open boundaries of the models are of great importance to the modelers.

As the HN modelers are convinced how well the models can and do reproduce the conditions in nature and as the method of "Wirkungspunkte" has shown ways and means for determining areas and locations where measurements should be made, it was considered that the HN models should be run before any extensive field investigation or expedition is initiated, in order to determine where to measure, what to measure, and when to measure. This would save much national and institutional funds and produce more applicable and more scientifically valuable results. A recommendation to this effect was prepared.

T. Laevastu

14. REQUEST FOR A MANUAL ON HN MODELS AND POSSIBILITIES FOR OBTAINING FUNDS FOR WRITING THIS MANUAL

The participants agreed that there is a substantial need for a manual on HN methods. The main purpose of it should be to propagate the knowledge and information on numerical activities world-wide, to describe the layout of the different HN models, typical grid sizes, computational effort, computational difficulties, and applications. It became obvious that this work could not be done by one person alone, but by a collection of different authors, to be edited by a competent scientist of this field. It was proposed that the collection of contributions and scientific editing should be done by Dr. Taivo Laevastu. Among the participants, Mungall, Callaway, Crean, Schmitz and Sündermann agreed to provide initial contributions to this volume. In addition, Dr. N. Heaps suggested establishment of a very complete bibliography on published HN models.

The participants agreed, also, to convince the several national representatives of IAPSO to establish a permanent IAPSO committee on HN models. The main purpose of this should be information, coordination, and avoidance of "model inflation." A recommendation was prepared in this matter.

J. Sündermann

VII. DISCUSSION OF THE ORGANIZATION AND PRESENTATION ON THE OPEN MEETING

It was decided that the principal results of the workshop and the works done with HN models in Europe be presented during the first day of the AGU meeting. The HN models are less known and used in the United States than in Europe and it was felt important that European results be brought to American scientific and technical audiences, especially as the results have not been, in general, described in scientific journals, but in technical publications with limited distribution. The second day was left for presentation of contributed papers and the third half day for discussion of resolutions and general discussions, as it was thought that many people would be leaving the third day for the AGU meeting in San Francisco.

T. Laevastu

VIII. THE FOLLOW-UP ACTION NEEDED

It was considered that periodic meetings on HN models be held in order to exchange experiences and results. It was considered that the audience and the number of participants would increase year after year and that ways and means must be found to organize the workshops and meetings to accomodate this increase.

T. Laevastu

APPENDIX A TO PART I
AGENDA OF THE HN MODEL WORKSHOP

GENERAL CHAIRMAN AND CONVENER - PROFESSOR WALTER HANSEN (HAMBURG)

AGENDA ITEMS, SUBJECTS	DISCUSSION LEADERS AND RECORDERS
I. OPENING	
1. Welcoming address	Captain R.C. Sherar
2. Opening remarks	Hansen
2.1 Introduction of participants, informality of the meeting, aims for accomplishments	
2.2 Discussion on agenda	
2.3 Discussion on the nature of the proceedings and their reproduction	
2.4 Discussion leaders	
2.5 Rapporteurs for open meeting	
3. The "necessities" (Accomodations, eating places, expense claim, dictaphones, parties and excursions)	Laevastu
II. REVIEW OF PAST HISTORY AND PRESENT STATE OF ART OF THE HN MODELS	
1. The basic model (incl. definition of HN and related models, finite difference forms, gird, etc.)	Hansen, Bauer
2. The driving forces; open boundaries and their treatment.	Laevastu, Duun-Christensen
3. Verification of results	
3.1 Sea level, currents	Callaway, Larson
3.2 Adjustment and verification of models by use of cross-spectral analysis	Liu, Voogt

4.	Multi-layer and multi-level models	Engel
5.	Specific scientific tests	
5.1	The method of "Wirkungspunkte"	Maier-Reimer
5.2	Wave deformation during computation and its prediction	Liu, Voogt

III REVIEW OF PAST APPLICATIONS AND FUTURE NEEDS

1.	Storm surges, sea level and depth predictions	Schmitz, Heaps
2.	Effects on coastal construction	Hansen, Laevastu
3.	Currents, pollutants	Callaway, Harding
4.	Mathematical models of turbulence	Sundermann, Engel
5.	Net circulation predictions	Sundermann, Heaps
6.	Design of engineering computation system	Liu
7.	Application of the method "Wirkungspunkte"	Hansen, Engel
8.	Sediment transport	Sundermann, Matthews

IV DISCUSSION ON POSSIBLE NEEDS FOR AN INTERNATIONAL OCEAN MODEL OPERATIONS CENTER (OR OPERATIONAL OCEAN ANALYSIS/FORECASTING CENTER)

Hansen, Laevastu

(Insufficienty of single national needs and funds, lack of service organizations in oceanography; identification of international needs (shipping, pollution); effects of ocean on weather and vice versa, including hydrological forecasts). Recommendations

V. IDENTIFICATION OF EXISTING, NOT FULLY EXPLORED PROBLEMS WITH HN MODELS, PRESCRIPTIONS OF EXPERIMENTS, AND PRIORITIES FOR RESEARCH

This is the primary reason for the workshop and should include (but not be limited to) discussions on the following topics:

1.	Comparison of finite difference versus finite element method	Sundermann, Leendertse
2.	Comparison of various types of existing multi-layer HN models	Schmitz
3.	Comparison of various treatments of multiple boundaries and use of the model with four open boundaries for open ocean areas	Bauer
4.	Selection of the best dispersion and diffusion formulation	Maier-Reimer, Callaway
5.	Aspects of energy transfer from one frequency to another	Voogt
6.	The determination of the need for inclusion of convective terms in small scale models	Sundermann, Voogt
7.	Treatment of internal friction and horizontal viscosity	Larson
8.	Use of "False bottom" in the models (to increase the time step)	Laevastu
9.	Comparison of methods of wind stress and oil dispersion computations	Schmitz
10.	Treatment of "vanishing layers" (e.g. upwelling) and computation of tidal flats	Leendertse
11.	Coupling of HN models with tide generating models and atmospheric models	Heaps, Duun-Christensen
12.	Effect of coarseness of the net on the results, and nested grids	Mungell, Crean

13.	Verification (and data) needs and need for pre-experimental model runs	Matthews
14.	Request for manual on HN models and possibilities for obtaining funds for writing this manual	Sundermann, Voogt
15.	Other problems	

VI. DISCUSSION OF THE ORGANIZATION AND PRESENTATION ON THE "OPEN MEETING"

(Including further discussion on preparation of proceedings and recommendations). Matthews

VII DISCUSSION ON "FOLLOW-UP ACTION WHICH MIGHT BE DEEMED NECESSARY

Hansen

APPENDIX B TO PART I
HN MODEL WORKSHOP
LIST OF PARTICIPANTS

CANADA

P.B. Crean
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PART II
REPORT ON AGU TOPICAL MEETING

REVIEW MEETING ON HYDRODYNAMICAL-NUMERICAL MODELS FOR COASTAL AND OPEN OCEAN AREAS

MONTEREY, CALIFORNIA 9-11 DECEMBER 1974

1. BACKGROUND, OBJECTIVES, AND AGENDA

The objectives of the AGU Topical Meeting were to propagate the results from the preceeding Workshop on Hydrodynamical Numerical Models and review the state of the art with these models in Europe and in North America. The meeting was sponsored by AGU, and arrangements were made by Environmental Prediction Research Facility, Monterey. The meeting consisted of three parts as the following agenda shows:

1.1 AGENDA PART 1 - REVIEW OF HN MODEL WORKSHOP

Chairman, Hansen

(1) Review of the HN models, formulas, finite difference methods, grids. Hansen, Heaps

(2) Past experiences and applications.
  2.1 Storm surges, (including negative surges) Duun-Christensen, Heaps
  2.2 General water body management, including pollution. Crean, Engel, Larson
  2.3 Sand transport, diffusion. Maier-Reimer, Harding

(3) Specific problems
  3.1 Open boundaries. Voogt, Mungall
  3.2 Driving forces, winds. Schmitz

(4) Multilayer and multilevel models. Heaps, Engel

(5) Specific applications.
  5.1 Design of engineering computation systems. Voogt

1.2 AGENDA PART 2 - CONTRIBUTED PAPERS Chairman, Hansen

Bauer, R.	Development of a Multi-purpose Multi-layer Hansen-type Hydrodynamical-Numerical Model.
Kollmeyer, R. and Paskausky, D	Baroclinic, Open Boundary, Labrador Current Prediction Model.
Bryan, K.	Flow Over Bottom Topography.
Hurlburt, H.E. and Thompson, J.D.	Open Boundary Conditions for a Two-Layer Hydrodynamical Ocean Model.
Hastings, J.R.	Hydrodynamical Study of the Eastern Bering Sea Shelf.
Gedney, R.T.	Numerical Model for a Stratified Lake.
O'Brien, J.J. and Peffley, M.B.	A Numerical Model of Coastal Upwelling Circulation Incorporating Oregon-like Bottom Topography.
Hamilton, P.	A Two-Dimensional Numerical Model of the Vertical Upwelling Circulation for a Continental Shelf, Assuming Long Shore Uniformity
Sengupta, S., Lee, S. and Veziroglu, T.N.	Near and Far-Field Models for Coastal Areas.
Spaulding, M. and Swanson, C.	Development of Tidal Current and Height Charts for Narragansett Bay, Rhode Island, Using a Two-Dimensional Vertically Averaged Numerical Tidal Model.
Rabe, K.	Reproduction of Wind, Tidal and Permanent Currents in the Puerto Rico Operating Area.

1.3 AGENDA PART 3 - GENERAL CONCLUSIONS AND RECOMMENDATIONS

Chairman, Matthews

2. REVIEW OF THE HN MODEL WORKSHOP

2.1 HN MODEL APPLICATIONS IN EUROPE AND REVIEW OF PRESENT STATE AND FUTURE APPLICATIONS Chairman, Professor Walter Hansen, Hamburg

a. Professor Walter Hansen, University of Hamburg, Germany

Professor Hansen led the discussions with a review of the development of the HN model, its present status and future applicability and problems. The analytical solution for hydrodynamical equation is possible only in very simplified conditions. The boundary value approach with hydrodynamical equation was introduced in the 1920's. The finite difference methods were proposed in 1938 by Hansen and the first numerical attempts were made in the middle 1950's with the availability of the first practically useful computers. Thereafter, intensive work with the HN models started.

At present the HN models are applicable to any area of the ocean and the application and reproduction of the real conditions in the ocean with these models depends mainly on the accurate description of the open boundaries. Some difficulties exist in obtaining good boundary inputs from measurements and in many cases they have to be estimated from available data by extrapolation or by using of transfer functions related to internal measurement points. Principally, however, HN models are operationally useful for solving most problems of sea level and current prediction. At present they have been combined, also, with the analysis/prediction of conservative and semi-conservative properties, such as salinity and temperature.

Examples of the application of the HN models from the University of Hamburg were presented for the Adriatic Sea, the North Sea and Northumberland Strait, together with the verification of the results from available data. Another recent application presented by Professor Hansen was the computation of the tides in world oceans using a 1° grid. The preliminary results were very promising indeed.

A new and promising method and area of the use of HN models is the so called method of "Wirkungspunkte". In this method a disturbance of a partial driving force, in one or a few grid points, or tide at a single station, is described, which will propagate all over the computation area. The manner of propagation can be followed in detail. The results show that the disturbance propagates from some limited areas in certain directions, and can spread out widely. However, from some other points, the disturbance does not propagate to any considerable degree. Thus, it is possible to determine the ocean/sea areas which are in relative rest and those which are in unrest. Furthermore, this method will allow the determination of locations where measuring and recording points are of importance and should be established, and where measurements are less important. Furthermore, the method clearly indicates the effects of bathymetry and coastal topography on the propagation of disturbances. It was proposed that this method be applied to investigate the effects of climatic changes, especially in respect of the effect of slight changes in wind field on ocean surface currents and hence the transport of heat (i.e., the climatic changes).

b. Dr. N. Heaps, Liverpool, United Kingdom

Dr. Heaps reviewed the principle results of the HN model workshop. He divided the results of the workshop into six different categories:

(1) The past applications of the HN models have been mainly in estuaries and semi-closed seas, where the validity and utility of the model has been demonstrated. Future work should also be directed to solve important problems on the continental slope areas, as well as in open ocean areas,

for which the beginning has been made and approaches indicated.

(2) The workshop emphasized the importance of convective terms in small scale models, especially in the reproduction of details of currents.

(3) The need to couple the HN model with the atmospheric models via sea-air interaction was emphasized. The need for closer collaboration between the meteorologists and oceanographers was expressed.

(4) The workshop emphasized, also, the need to bring the modelers and the descriptive oceanographers closer together. Both require each other. The modelers want input for boundaries and data for verification of the models, and the empirical oceanographers need models to design observational networks and decide on optimum locations for recording stations.

(5) Two different modes of the use of the HN models was emphasized. First, as a research tool, which involves the numerical and mathematical understanding of the model and its formulation.. The second problem involves the practical understanding and application of the model, requiring a team work between the observers, analysts and modelers. Thus, it is not desirable to consider the numerical modelers as a separate and special group. They should be integrated with oceanographers and meteorologists and should have the proper basic background in the two sciences.

(6) Among the necessary further developments, the following were singled out:

(a) Further development of 3-dimensional models, combining multi-level and multi-layer designs.

(b) Comparison of the finite difference and finite element approaches and/or finding other ways to cut computer core and time requirements.

(c) Experimentation with the variable grid size in the models.

(d) Preparation of manuals on HN models and the conduct of training and education in the use of these models.

2.2 PAST EXPERIENCES AND APPLICATIONS

2.2.1 Storm Surges (including negative surges)

a. Eng. Duun-Christensen, Copenhagan, Denmark

Eng. Duun-Christensen presented results of a Hansen type storm surge prediction model for the North Sea and Skagerrak-Kattegatt which is ready for operational use in Denmark. The need for storm surge prediction with HN models was emphasized whereas the limitations of the presently used empirical formulas was pointed out. The Danish Hansen type model obtains meteorological input from a small grid (150 km) meteorological analysis/prediction program. The surface wind is obtained with a nonlinear equation, derived from Hasse's equations. The results of running hindcasts for a number of storms surges in the North Sea have given satisfactory results indeed; where discrepancies have been observed, they are mostly caused by inaccuracies in meteorological input.

b. Dr. N. Heaps, Liverpool, United Kingdom

Dr. Heaps described the new United Kingdom model for storm surge and sea level prediction. An additional objective of the model is to predict the depth of the water in important navigational areas such as the English Channel and predict the sea level for Thames Estuary Barrier operations.

The open boundary inputs for this model are derived using deep water tide measurements at the continental slope, north and west of the British Isles. The meteorological input is obtained from a 10 level PE model with an 80 km grid size, operated by the Meteorological Office of United Kingdom. The input is obtained from 12 to 36 hour predictions.

Dr. Heaps showed some examples of the hindcasting of storm surges in the North Sea, and described the effect of a meteorological front on the storm surges. It was emphasized that the wind and pressure fields near the fronts must be accurately prescribed in order to obtain accurate results.

2.2.2 General Water Body Management, Including Pollution

a. Dr. P. Crean, Vancouver, Canada

Dr. Crean described the need for the application of HN models for the water in the Strait of Georgia, including the formation of the bottom waters and the fate of pollution in this area. A 2-dimensional model for the Strait of Georgia was used with 1-dimensional appendages of Puget Sound and some of the British Columbia Inlets. In order to obtain correct results, the reproduction of the channels in the San Juan Islands area and frictional effects of these areas is of great importance. To solve the practical problems, both empirical observations and numerical modeling were used, and the excellent results of a properly tuned model was demonstrated. Further work will include the comparison of measured and computed currents in the Strait of Juan de Fuca and in the narrows between the islands from Vancouver Island via the San Juan Islands to the Mainland.

b. Dr. M. Engel, University of Hamburg, Germany

Dr. Engel described examples of the application of HN models in Hamburg and Hannover. He showed comparisons of results obtained from finite difference and finite element methods, indicating that at present nothing has been gained in applying the finite element method. Dr. Engel demonstrated the need to include convective terms in small scale models if it is important to reproduce details of current structure, such as eddy formations around islands and near headlands.

c. Mr. S. Larson, Monterey, California

Mr. Larson showed examples of HN model application in EPRF, Monterey, including the application to New York Bight in relation to sewage and sludge disposal problems; computations of currents and flushing in San Diego Bay and a comparison of the results to those obtained with a physical model; and application of the HN model to open ocean areas with three and four open boundaries. Special applications were made for Strait of Florida where permanent current was introduced at one open boundary. The model ran for 72 hours, until equilibrium conditions were established. Thereafter, the boundary values for three open boundaries with the permenent currents were introduced into the tide and wind current model. Some good verification from direct current measurements in this area were also presented. Mr. Larson explained the treatment of the multiple open boundaries in case exact boundary values are not available.

2.2.3 Sand Transport, Diffusion

a. Dr. E. Maier-Reimer, Hamburg, Germany

Dr. Maier-Reimer showed results of the application of an HN model for the computation of sediment transport in the North Sea. The main part of his presentation dealt, however, with the solution and comparison of various solutions of numerical computation of the diffusion in HN models. He compared the Eulerian and the Lagrangian solutions and presented the Monte Carlo method, which seems to present the diffusion and dispersion in the most realistic manner.

b. Mr. J. Harding, Monterey, California

Mr. Harding described a Danish method of transport and diffusion-dispersion computation with an HN model, which is absolutely conservative and produces the results in a realistic manner. The only drawback of this method is the rather large computer core and time requirement.

2.3 SPECIFIC PROBLEMS

2.3.1 Open Boundaries

a. Dr. J. Voogt, Rijkswaterstaat, Netherlands

Open boundary conditions of hydrodynamical-numerical models are usually given as time histories of water levels or current velocities or a combination of these. When observations are missing, artificial boundary data can be used for model development. But adjustment of the model can only be successful when using observed data, for eventually model behavior should approximate the real prototype situation. Moreover, the sum of the effects of the different tidal components is not equal to the effect of their sum, due to the nonlinear character of tidal propagation in shallow water.

Unfortunately, the observed values are usually rather noisy, e.g., the water level measurement by pressure gauges on the sea bottom is disturbed by (1) instrument inaccuracy, (2) meteorological effects and (3) short-period waves (swell). Presently, the noise in the observations can be removed by applying cross-spectral analysis.

The application of this method is illustrated for the case of a coastal model of the North Sea, north of the Dutch Waddenzee. Here the hourly tide levels were strongly disturbed by a heavy swell coming from the northern North Sea. By taking a reference station in the middle of the area, relations could be established for the different tidal components between the boundary stations and the reference station. These relations are the amplification of the amplitude going from the reference station to the boundary station and the phase lag between the components in the two stations. A measure of the correlation existing between the components in the two stations is given by the coherency squared. An extensive description of the method of cross-spectral analysis and its application will be given in the Proceedings of the Coastal Engineering Conference in Copenhagen, 1974, in the paper by S.K. Liu, J.J. Leendertse, and J. Voogt: Estimation of Boundary Conditions for Coastal Models.

b. Dr. J. Mungall, Texas A & M University, Texas

Dr. Mungall described the radiation boundary condition and its possible use in hydrodynamical numerical models. The method has been used earlier in physics and in some other models in Texas A & M. It is, in many ways, similar to one of the approaches used in EPRF, Monterey, and thus provides a theoretical background to the Monterey approach. His paper will be reproduced in "HN Model Digest".

2.3.2 Driving Forces, Wind

a. Dr. H. Schmitz, Offenbach, Germany

Dr. Schmitz described the input of wind into HN models and pointed out the insufficiency of present surface wind data. A much smaller grid is required for the meteorological analysis from which good wind data can be obtained. He proposed the use of advective models to obtain good surface pressure analysis for the first 18 hours. The grid size in such a model should not exceed 100 km. Furthermore, it is necessary to obtain the true surface analysis and wind rather than 1000 mb or 900 mb level winds, as is the case at present.

Dr. Schmitz, furthermore, pointed out that the small drag coefficient which occurs very often in literature (1.5×10^{-3}) is not used in HN models, but the drag coefficient which gives reasonable results is between 2.6 and 3.0 10^{-3} (Palmen's coefficient). Dr. Schmitz also described the difficulty of obtaining true surface wind from geostrophic wind as it depends on many factors such as stability, rate of pressure change, etc.

2.4 MULTI-LAYER AND MULTI-LEVEL MODELS

a. Dr. N. Heaps, Liverpool, United Kingdom

Dr. Heaps described a multi-level model which he has applied to the Irish Sea. He showed results of computations with different winds and verifications obtained by measuring potentials in telephone cables. The model shows the complexity of wind currents as influenced by bottom and coast configurations.

b. Dr. M. Engel, Hamburg, Germany

Dr. Engel described the results from a 3-D (two layer) model of the North Sea. In this model he had prescribed the mixed layer depth which caused a circulation in the surface layer as theoretically expected. The results of the computation of tidal currents with the 3-D model showed a good verification with the available empirical data.

2.5 SPECIFIC APPLICATIONS

a. Dr. J. Voogt, Rijkswaterstaat, Netherlands

Dr. Voogt described the engineering computation system using HN models as is presently in use in Rand Corporation and in the Rijkswaterstaat in Holland.

Summarized by
T. Laevastu

3. ABSTRACTS OF CONTRIBUTED PAPERS

DEVELOPMENT OF A MULTI-PURPOSE MULTI-LAYER HANSEN-TYPE HYDRODYNAMICAL NUMERICAL MODEL

by

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Hydrodynamical-Numerical (HN) Models have been developed for specific coastal areas using a variety of techniques for handling boundary value inputs. To make operational use of HN models in new areas feasible, a generalized model has been devised that permits multiple open boundaries, variable grid sizes and the use of 1 to 3 vertically integrated layers.

The computational procedures within the model are optimized, reducing computer costs significantly. The main HN computer model has been reduced in size by elimination of all auxiliary computations and produces a simple set of water height, velocity terms which are stored at frequent intervals on magnetic tape and can be used to restart the model after any previously computed time step. Auxiliary operations, including an extensive graphics display package, computation of rest currents, and transport through sections are then applied to the HN results on magnetic tape.

The process of preparing multi-layer land-sea grids has also been automated, greatly reducing the time and cost of setting up new areas.

Work is in progress on linking the HN model with realistic variable wind input and extension of potential application by incorporation of a variable Coriolis capability. Further work is in progress to couple the HN model data results with advection and diffusion schemes. Results obtained from the HN model and preliminary results of work in progress show great promise.

BAROCLINIC, OPEN BOUNDARY, LABRADOR CURRENT PREDICTION MODEL

by

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A four-layered, baroclinic, open boundary, prognostic, numerical flow model is applied to a region immediately east of the Grand Banks of Newfoundland. The model employs: the momentum and continuity equations vertically integrated in each layer; stress coupling between layers; advection and diffusion of temperature and salinity; and wind stress on the surface layer. A grid spacing of 5 km is used over an irregular bottom with model depths ranging from 70 meters on the Continental Shelf to 1000 meters in deeper water.

Data from three hydrographic surveys in a 1.2 X 10^4 km^2 region of the North Atlantic, spaced approximately 7 days apart, are used as initial conditions and for verification comparisons of predicted property distributions. The initial conditions are used to compute current velocities from a diagnostic model which in turn is used in a predictive fashion allowing the properties to change with time as advection and diffusive mixing occurs in three dimensional space. The property conditions on the lateral boundaries are changed linearly during the prediction time intervals as exhibited by the inflowing currents at the time of each survey. Transient local winds obtained from daily weather maps are applied during the model's operation.

The selection of lateral and vertical frictional coefficients is critical in controlling the current velocities and cross stream gradients of flow. Mesoscale changes in the circulation features as indicated by the property distributions within the Labrador Current and Gulf Stream appear correctly predicted by the model when compared to actual survey conditions.

FLOW OVER BOTTOM TOPOGRAPHY

by
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Analytic and three-dimensional numerical solutions for the flow of a stratified ocean over bottom topography are compared. Flow starting from rest generates an anticyclonic vortex over the obstacle, and a free cyclonic vortex downstream of the obstacle. Depending on the speed of the flow the free vortex escapes downstream, or is held near the obstacle. The behavior is similar to what might be observed in a homogeneous rotating fluid, but the disturbed flow is confined near the bottom. A comparison is made between cyclic boundary conditions, and an open downstream condition with favorable results. The shed vortex passes through the open boundary without reflection.

OPEN BOUNDARY CONDITIONS FOR A TWO-LAYER HYDRODYNAMICAL OCEAN MODEL

by
H. E. Hurlburt
Postdoctoral Fellow, NCAR*
and
J. Dana Thompson
Postdoctoral Fellow, NCAR*

Unique open ocean boundary conditions have been incorporated in two-layer x-t and x-y-t primitive equation hydrodynamical ocean models. The models are time-dependent and retain the free surface, treating the barotropic and baroclinic wave modes implicitly in x and explicitly in y for the x-y-t model.

In the results to be presented the northern and southern boundaries are open and allow development of a Sverdrup interior when the model is solved on regions with mesoscale N-S extent. Total mass transport through the open boundaries is a specified quantity although the details of the flow are not specified.

Three basic model experiments were examined. In the first experiment a closed basin β-plane ocean was integrated over a meridional extent of 5000 km and a longitudinal extent of 3000 km. In the second experiment the same model was run with open basin boundaries located 1000 km to the north and south of the central latitude of the closed basin. Thirdly, an x-t model simulation was conducted along the central basin latitude with the same east-west extent as the former two models. In all three cases the solutions at the central latitude were remarkably similar. Further, the open-boundary solutions were in close agreement with

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*The National Center for Atmospheric Research is sponsored by the National Science Foundation.

the closed basin solution over the common domain.

We find the open ocean boundary conditions to be most useful in modelling a wide variety of ocean flows, including equatorial and coastal circulations.

HYDRODYNAMICAL STUDY OF THE EASTERN BERING SEA SHELF

by

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The eastern Bering Sea shelf has been studied using a hydrodynamical (HN) model. Relative sea-level perturbations and resultant currents have been determined at the end of one, two, three and four complete tidal cycles. Currents in the central part of the Bering Sea are found to be generally less than 10 cm/sec, which corresponds closely to actual speeds found in the natural system. Summer wind conditions are represented by imposing a mean southerly wind of 5 cm/sec over the entire computational grid. Rest currents after three and four tidal cycles show the general anti-cyclonic circulation over most of the Bering Sea shelf, with several gyres appearing in the overall circulation pattern. A south-to-north slope of approximately 10^{-6} is indicative of that found in the natural system. Comparisons of computed valves with actual environmental measurements gives an indication of the relative accuracy of the application of a hydrodynamical model to this particular environmental system.

NUMERICAL MODEL FOR A STRATIFIED LAKE

by

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A Numerical model for the time-dependent, three dimensional, variable-density and variable-temperature wind driven circulation in a square lake is developed. Steady-state results are presented showing the effect of spacial variation in wind shear stress over the lake and the effect of variation in bottom depth on the circulation in a strongly stratified shallow lake. The position of the thermocline and hypolimnion velocity magnitudes are strongly dependent on the spacial variation of wind shear and bottom depth as was previously predicted by a much simpler two layer stratified lake model. Therefore, in comparing the model results to actual data it will be important to model quite accurately the wind field and the lake bottom depth.

A NUMERICAL MODEL OF COASTAL UPWELLING CIRCULATION INCORPORATING OREGON-LIKE BOTTOM TOPOGRAPHY

by

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The x-y-t two-layer, primitive equation, β-plane model of eastern ocean circulation developed by H. E. Hurlburt has been used to investigate the onset of coastal upwelling on the Oregon shelf. The model's efficient semi-implicit numerical scheme, variable resolution grid and unique open-basin boundary conditions allowed high resolution (Δx = 4 km, Δy = 10 km) of the digitized x, y-dependent Oregon bottom topography and coastline.

Comparison of a flat bottom case to those with topography reveal a much stronger dependence of upwelling on topography than on coastline irregularities. Several observed features of the Oregon coastal upwelling regime are also observed in the model solutions. A near-shore equatorward jet develops in the upper layer, accompanied by a poleward under-current in the lower layer. With winds shut off, the undercurrent strengthens. Shelf waves are seen in the model solutions as northward propagation of the upwelling areas. North-south sloping topography of the Oregon region provides, in some areas, a more severe vorticity constraint than that of β.

The necessary compromise between resolution of long-shore scales and regions of large bottom slope on the one hand and economy on the other is discussed for this specific example of y-dependent topography.

A TWO-DIMENSIONAL NUMERICAL MODEL OF THE VERTICAL UPWELLING CIRCULATION FOR A CONTINENTAL SHELF, ASSUMING LONG SHORE UNIFORMITY

by
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An extension of a finite difference method which has been successfully used for estuarine circulation studies, is applied to the problem of the wind-driven upwelling circulation on the continental shelf. The usual hydrodynamical equations, including the equation of advection and diffusion of mass, are used with the assumption of long shore uniformity. A finite difference grid is arranged in the vertical plane and the equations solved by a one time-step semi-implicit method. Thus the model gives the baroclinic and barotropic response of shelf waters to an applied wind stress along with the density structure, for variable bottom topography, under various conditions of mixing and stratification.

NEAR AND FAR-FIELD MODELS FOR COASTAL AREAS

by

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University of Miami

A comprehensive numerical model development program for near-field thermal plume discharge and far-field general circulation in coastal regions is underway at the University of Miami. The objective of the research is to develop predictive models for thermal pollution studies. Two regions of specific application of the models are the Biscayne Bay and Hutchinson Island areas along the Florida coastline.

It is numerically cumbersome to model the general circulation together with the thermal plume flow field. The stability criteria and the programming details are markedly different for the general circulations and the near-field jet-like thermal discharges.

The problem has therefore been divided into more tractable parts whose results are to be synthesized for the overall model.

(a) A one-dimensional study of the energy equation with no horizontal diffusion or convective terms. The results will be compared with field data. Conclusions regarding the magnitude and variation of the vertical eddy diffusivity can be made from this study. The solar radiation boundary condition and the form of the source term in the energy equation should also be available from this study.

(b) A rigid-lid model for Biscayne Bay has been developed and wind driven circulation patterns have been calculated. Effects of tidal boundary conditions and buoyancy are being incorporated.

(c) A free surface model including tidal boundary conditions will be the final general circulation model. This is imperative where the coastline is directly open to the sea. The velocity and temperature fields obtained from this will be used as the far-field solution for the thermal discharge model. A vertical stretching which maps thy variable depth, variable wave height region to a constant depth region is being used.

(d) The near-field region for the jet discharge is being modelled using both the rigid-lid and the free surface approach. Vertical stretching is used in both approaches to map the domain to constant depth.

The numerical results are being compared with ground-truth measurements as well as remotely-sensed infra-red data from aircraft and satellite systems.

DEVELOPMENT OF TIDAL CURRENT AND HEIGHT CHARTS FOR NARRAGANSETT BAY, RHODE ISLAND USING A TWO DIMENSIONAL VERTICALLY AVERAGED NUMERICAL TIDAL MODEL

by
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Employing a two dimensional vertically-averaged numerical tidal model, currents and tide heights were predicted for Narragansett Bay, Rhode Island and showed reasonable comparison to existing U.S. Coast and Geodetic charts. Further verification using flow rates across the west passage showed good results. Employing the model, tidal ranges varying from 1.6 to 6.0 ft. were employed as the driving force for the lower boundary. Simple scaling factors to correct tide height and current velocities (based on a 3.5 ft. range) were determined for these ranges. Determination of these scaling factors allows for the rapid estimation of tidal conditions by simple knowledge of the tidal range for the day in question.

REPRODUCTION OF WIND, TIDAL AND PERMANENT CURRENTS IN THE PUERTO RICO OPERATING AREA

by

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A single-layer hydrodynamical-numerical model of the Hansen-type was run for an area encompassing the island of Puerto Rico and its surrounding waters, a four open boundaries situation. A mesh length of 11.2 km and a time step of 24 seconds were used in the calculations. A permanent east-to-west flow of approximately 25 cm sec^{-1} was simulated by super-imposing a transverse slope on the field. The tidal constituents from San Juan were interpolated to the upper boundary and used to generate the tidal flow. The current fields were computed for out to 35 hours and the surface elevation and current speed and direction for twelve points of interest were obtained in graphic form.

APPENDIX A TO PART II
SUMMARY

The HN Model Workshop was held in the U.S. Navy Environmental Prediction Research Facility, in Monterey, California, from the 2nd to the 7th of December 1974, and was sponsored by a small grant from Office of Naval Research (ONR). The Chairman and Convener was Professor Walter Hansen from the University of Hamburg. There were 28 participants from USA, Europe and Canada in the workshop, most of whom were scientists who have had considerable experience with the development and application of HN models.

The objectives of the workshop were: (a) to review the progress made in the last decade in the development and application of the HN models; (b) to compare different approaches used, especially in numerical solutions of the problem, (c) to discuss solutions to problems encountered in the application of the HN models for various areas and conditions, and (d) to recommend action in comparing and/or devising plausible satisfactory solutions to these problems.

The Hydrodynamical Numerical model is defined as a numerical model which uses the hydrodynamical formulas (equations of motion and continuity) with numerical solution to real conditions in the nature, i.e., with real depth and bottom configuration and real environmental input data in space and time.

The discussions concerned three slightly different types of HN models, especially with respect to the numerical solutions, which can be classified as the Hansen Type, Leendertse Type, and Heaps Type models. Both the multi-layer and multi-level models are in use.

The principle application of HN models can be divided into four main categories. The first category concerns routine operational application of the HN model (mainly in Europe) for storm surges, sea level, and actual depth and current predictions. The second type of application is for water quality control, including pollution problems (Rand Corporation, (Leendertse) and in Canada (Crean)). In these two categories of application, the selected area of model application is usually unchanged and continuous improvement and testing takes place in the same area and program. The third category of application occurs in Environmental Prediction Research Facility, in Monterey, where the models are used to obtain data for a great number of areas on currents, tides and related subjects, otherwise not available from measurements. The boundary input data for the areas are obtained by extrapolation of available tide data, mean currents and winds and by tuning the model with available measurements within the computation area. The fourth category of application is for research purposes, including further testing and developing of the model, and for application of specific problems such as sediment transport and especially for investigation of the areas where the driving forces and disturbances are of importance i.e., the "Wirkungspunkte" method for the design of observation networks.

Of the specific discussions in the workshop, the following were of primary concern: (a) the treatment of open boundaries and of obtaining proper open boundary input; (b) internal friction problems in multi-layer and multi-level models; (c) the comparison of finite difference versus finite element methods; (d) the necessity of including convective terms, and (e) the treatment of the vanishing layers.

Among the more general subjects related to HN models, the following were ventilated: (a) the need to cooperate more closely with meteorologists with respect to better input of meteorological driving forces; (b) cooperation with empirical and descriptive oceanographers to obtain input and verification data; (c) to use the models for the purpose of designing an observation network and other observational parameters; and (d) to explore other possibilities of application of the method of "Wirkungspunkte", both in the scientific and the applied field.

The open meeting under AGU auspicies drew about 70 participants. The first part of the meeting consisted of a review of the results from the workshop, as well as a presentation of the work with HN models -- especially those from Europe. Professor Hansen gave an introductory lecture on HN models in general. He pointed out that the first numerical attempts were made in the middle 50's, whereafter, intensive work with HN models started. Hansen pointed out that the HN models are principally dependent upon accurate descriptions of the open boundaries, for which empirical measurements are required. The HN model, at present, can be used not only for the prediction of sea level and currents, but also, for predicting the distribution of temperature, salinity and pollutants. He gave examples of the applications of HN models in various areas, at the University of Hamburg. One of the latest works is the computation of tides in the world oceans and the application of the methods of "Wirkungspunkte" in connection with the HN model. This method allows the determination of the areas in the ocean which are at rest and those which are in unrest. He emphasized the further possibilities of the application of this method for such problems as the study of the climatic changes with respect to oceanic feedback.

Dr. Heaps, from Liverpool, reviewed the proceedings of the workshop. He pointed out that the past applications of HN models have mainly been in estuaries and semi-closed seas. The present and future work is also directed to oceanic areas and continental slope areas where many scientific as well as practical problems exist. The open ocean models must be coupled with atmospheric models involving sea-air interaction. It was recognized in this connection that closer cooperation between meteorologists and oceanographers must be established. Furthermore, the importance of an observational network was emphasized by Dr. Heaps, especially with respect to obtaining boundary values, as well as verification of the model, thus requiring close collaboration between empirical and descriptive oceanographers and the modelers.

With respect to other developments, the following were emphasized by Heaps: (a) development of 3-D models, both with the multi-layer and multi-level approach; (b) comparison of the finite difference and finite element methods; (c) solution of the variable grid problem; and (d) preparation of a manual on HN models and provision for training and education in their use.

Dr. Heaps described the new United Kingdom model for storm surge and sea-level prediction. The boundary inputs for this model were obtained from off shore measurements at the continental slope. The meteorological data were obtained from an 80-km grid, 10-level PE model from Bracknell. Heaps emphasized the necessity of describing the wind field with great accuracy in the case of passing fronts. He also described a multi-level model for the Irish Sea showing the complexity of wind-driven currents.

Mr. Duun-Christensen, from Copenhagen, demonstrated the application of the Hansen type model for the North Sea used in prediction of storm surges. He also emphasized the need for accurate meteorological inputs.

Dr. Crean, from Vancouver, described the application of an HN model for water management and the exchange of water between coastal and offshore waters in the Strait of Georgia. His model, at present, is a 2-D model with 1-D appendages for Puget Sound and Canandian inlets. He demonstrated how excellent results can be obtained from a model when it has been properly tuned, and outlined future verification work in the area.

Dr. Engel, from Hamburg, showed examples of the application of the HN model in the Universities of Hamburg and Hannover. He presented preliminary results on the comparison of finite difference/finite element methods, as well as describing the effect of convective term inclusions in the model. He also described an application of a two-layer model for the North Sea with pre-described thermocline topography.

Mr. Larson, from Monterey, showed examples of the application of HN models in the United States, especially with respect to obtaining currents and pollutant distributions and described the treatment of open boundaries if and when accurate measurements are not available. Mr. Harding also described a new Danish advection equation which may be used in HN models.

Dr. Maier-Reimer, from Hamburg, showed some applications of the HN models for sediment transport and described in detail, several approaches to solve the diffusion problem in an HN model, especially in comparing Eulerian and Lagrangian solutions and showing excellent results with the so called Monte Carlo method.

Mr. Voogt, from Holland, showed that boundary values can be obtained by using empirical transfer functions and spectral analysis to correct estimated boundary conditions. He also described an engineering system for the application of HN models to coastal construction and pollution problems.

Dr. Mungall, from Texas A & M, described radiation boundary conditions.

Dr. Schmitz, from Offenbach, described the input of meteorological driving forces, emphasizing that the present input of wind is unsatisfactory and small grid meteorological models are required as counterparts of HN models. He proposed that an advective meteorological model be used for the first 18 hours with the grid size not exceeding 100 km. He also explained that the small conventional drag coefficient is not used in HN models, and the reasons for it are not certain yet. Finally, he emphasized that the determination of true wind from geostrophic wind is, in many cases, too uncertain and depends on stability and a few other factors.

The second part of the meeting consisted of the presentation of contributed papers from the United States. Of great interest, was the paper by Dr. Kirk Bryan on the use of a model to design observational networks. The majority of the presented papers described initial numerical experimentation with models similar to HN models, indicating that the HN models are not fully known yet in the United States with respect to their capabilities and applicability. It is hoped that this meeting contributed considerably to making the models more widely appreciated.

The recommendations proposed and approved by the workshop and the AGU meeting are given in Appendix B.

APPENDIX B TO PART II

RECOMMENDATIONS FROM HYDRODYNAMICAL NUMERICAL MODEL WORKSHOP AND AGU TOPICAL CONFERENCE

The Hydrodynamical Numerical (HN) Model Workshop and AGU Topical Conference discussed thoroughly the scientific and practical aspects of Hydrodynamical Numerical models. From a scientific point of view, HN models deliver solutions of the hydrodynamical partial differential equations for oceans, marginal and adjacent seas and estuaries. The results of these models have been found to be in good agreement with measurements in a large number of areas. In order to encourage future development of HN models, both in scientific and practical aspects, the HN Model Workshop and AGU Topical Conference recommends:

1. That ways and means be explored to establish regional or inter-regional centers having available computer facilities where cooperative work on different kinds of numerical oceanographic models can be carried out and where both oceanographic and meteorological data necessary for this work can be available.

These centers could, furthermore, be used for general forecasting purposes, especially if they are combined with corresponding centers for cooperative work in the field of meteorology as, for example, the European Center for Medium Range Weather Forecasting in the United Kingdom.

2. That each field experiment and measuring program should be preceded by a numerical investigation in order to ascertain the most relevant points of the physics of the system in order to plan and organize the measurements and observations efficiently.

3. That further research and application of the method of "Wirkungspunkte" (points of influence) be effected as

soon as possible to ascertain its utility in determining the areas (and "points") in the oceans and in coastal waters which are in relative rest and those which are in unrest, especially with respect to propagation of disturbances. This method might become a valuable tool in the design of field observations (e.g., IGOSS). A further prospective application of this method is in a determination of the effects of dislocation and changes of intensity of the driving forces of the oceans (especially winds and heating/cooling) on long-term climate changes. It is recommended that the latter approach be tested as soon as possible.

4. That further study of the performance of the different HN models for tides, storm surges, pollutant dispersion and other applications be applied to areas for which extensive oceanographic and meteorological data is available so that hindcasting experiments may be attempted. These areas might include the North Sea and adjacent waters, the Strait of Juan de Fuca, the Strait of Gibraltar, Lake Erie, selected areas off the Oregon, California and Florida coasts, the New York Bight, Chesapeake Bay, Mississippi delta, and the Grand Banks area.

5. That in order to apply HN models for pollution problems, more experimental techniques for the study of turbulence from a Lagrangian point of view be developed.

6. That the performance of the different numerical models, based on finite difference and/or finite element methods, be compared using the same input data and also that the advantages of combining multi-level with multilayer formulations be studied from a scientific as well as an applied point of view.

7. That further work on sediment transport problems with HN models be conducted in cooperation with coastal engineers and geologists.

8. That closer cooperation between meteorologists (and meteorological forecasting centers) and oceanographers working with HN models be established in order to find ways and means to satisfy each other's data needs including the accurate and timely input of meteorological driving forces into the HN models.

The real time HN models for storm surge prediction require that the following minimum demands on data be met:

a. The grid point distance of the meteorological grid must be as small as possible, but not to exceed 150 km.

b. The input of meteorological data to the HN model must be made at least every three hours.

c. The computed and/or analyzed surface winds must be accurate to ± 10% of the observed value. Special attention must be given to realistic presentation of winds and surface pressure in the vicinity of surface fronts.

9. That measurements and continuous recordings be conducted at the open boundaries of the HN model areas in order to obtain necessary input data for HN models, particularly those models which are or will be used routinely for surge and actual depth and current predictions. Long-term off-shore recording stations should be established at physically pertinent locations to measure tidal heights, currents and possibly other oceanographic parameters.

10. To prepare a manual of HN methods and their applications. As an initial step Dr. Laevastu (EPRF) was asked to edit such contributions as are forwarded to him. This organization will also try to handle the exchange of information on HN models and their applications.

The following recommendation was submitted to IAPSO via AGU from the HN Model Workshop and AGU Topical meeting:

"In recent years the development of Hydrodynamical-Numerical (HN) models has demonstrated a unique capability to provide realistic solutions to many oceanographic problems, often involving complex topography and non-linear behavior. Advances in computing technology hold singular promise of increasing capability at viable costs. Unquestionably, these techniques will play a major role in providing insights requisite to the successful management of the world's oceans, seas and estuaries.

The participants of the HN Model Workshop and AGU Meeting, therefore, recommend that IAPSO establish a Committee on Hydrodynamical-Numerical (HN) models of the oceans and their coastal fringes, which will provide a forum for cooperation in development and scientific application of HN models".

APPENDIX C TO PART II

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