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FLEET NUMERICAL WEATHER CENTRAL MONTEREY CA
SYNOPTIC NUMERICAL OCEANOGRAPHIC ANALYSIS AND FORECASTING PROGR--ETC(U)

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Outline
of

① SYNOPTIC NUMERICAL OCEANOGRAPHIC ANALYSIS
AND FORECASTING PROGRAMS. *Outline*

at

U.S. FLEET NUMERICAL WEATHER FACILITY

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Fleet Numerical Weather Facility
Monterey, California

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Contents

1. Introduction.
 - 1.1. Types of oceanographic analyses and forecasts classified according to purpose and type of user activity.
2. Outputs and programs for ASWEPS
 - 2.1. Sea surface temperature (SST).
 - 2.2. Sea and swell.
 - 2.3. Prognostic surface currents.
 - 2.4. Mixed layer depth (MLD).
 - 2.5. Subsurface thermal structure.
 - 2.6. Transient thermoclines.
 - 2.7. Surface air temperature and water vapor pressure (including visibility and fog probability).
 - 2.8. Sea - air heat exchange.
 - 2.9. Total heat exchange.
3. Explanatory notes.

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1. Introduction.

→ There is a practical need to establish numerical oceanographic analyses and forecasts, even though the quantitative knowledge of the processes in the oceans is still somewhat shaky in some subjects.

The available oceanographic knowledge was screened and evaluated, and the preliminary programs were suggested accordingly.

The meteorological programs and some oceanographic programs have been described elsewhere and are not repeated here. However, proper references to these descriptions are given herein.

Brief explanatory notes, consecutively numbered with Roman numerals, are given at the end of this outline.

Some of the selected approaches are rather empirical, compared to theoretical, unverified models proposed in the literature. Some simplifications also occur. However, the reproducibility of the nature and the availability of the synoptic data have dictated the selected programs to a large extent.

→ The following main principles were followed in the compilation of the enclosed program outlines and in suggesting the formulas and other approaches:

(1) The program must describe the conditions and behavior of the ocean as accurately, and in as much detail, as possible at the present stage of theoretical and empirical knowledge. All programs must be verified and adjusted accordingly.

(2) The required accuracy should be evaluated in the light of the knowledge of actual periodic and aperiodic fluctuations in relation to analysis intervals and grid sizes used.

(3) The programs should be flexible, allowing improvements and changes to be made when new knowledge becomes available.

(4) The main forces causing changes in the surface layers in the sea are of atmospheric origin, and therefore the available meteorological analyses and forecasts should be used to the fullest possible extent.

(5) The products of analyses and forecasts should be presented in the form in which they are most useful for the users. In fact, this is a first requirement in disseminating scientific and technical information to users and appliers.

1.1. Types of oceanographic analyses and forecasts classified according to purpose and type of user activity.

I. Surface phenomena. Forecasts used in navigation, fisheries work and a number of naval surface operations (such as amphibious operations, etc.).

- (1) Sea and swell, surf
- (2) Surface currents
- (3) Sea surface temperature
- (4) Fog and visibility
- (5) Ice
- (6) Tides

II. Subsurface phenomena. Used in submarine navigation and warfare and fisheries.

- (6) Mixed layer depth and subsurface thermal structure
- (7) Transient thermoclines
- (8) (Abundance of life and animal noises)

III. Sea - air exchange. Used as input into other forecasts, especially for improving and extending weather forecasts over the oceans, thus for ship routing, naval and fisheries planning, etc.

- (9) Heat exchange
- (10) Changes of the properties of surface air (temperature and humidity).

The present outline is mainly concerned with the programs for ASWEPS. However, in order to arrive at the desired analyses and forecasts a full line of analyses must be carried out. This is graphically illustrated in Figure 1. A simplified flow diagram for the analyses and prediction of subsurface thermal structure, which is the central subject of this memo, is given in Figure 2.

2. Outputs and programs for ASWEPS.

Needed quantities (outputs) of oceanographic programs on ocean thermal structure analyses and prediction are:

- *(*) (1) Sea surface temperature.
- ** (2) Mixed layer depth (depth of the seasonal and/or permanent thermocline).
- * (3) Temperature gradient within the thermocline.
- ** (4) Delineation of areas where transient thermoclines (or continuous density models) can be expected; plotted as

"anomalous" temperature increase (as compared to interpolated increase) in 24 hours, thus giving the probability of occurrence of transient thermoclines.

- (5) Temperature at the lower boundary of seasonal (and upper boundary of permanent) thermocline.
- (6) Gradient in permanent thermocline.
- (7) Temperatures at 30, 65, 100, 150, 200, 400, 600, and 1000m.

The quantities marked with * would have analyses only, and those marked with ** would have, in addition, forecasts for varying periods. Other computed quantities are prepared upon request or sent to other centers for sound speed computation and other reprocessing.

Computed processes, and analyzed distributions necessary for subsurface thermal structure prediction, which form separate outputs, are:

- (1) Surface air temperature over the ocean.
- (2) Surface water vapor pressure.
- (3) Geostrophic wind velocity field.
- (4) Sea - air heat exchange.
- (5) Total heat exchange.
- (6) Sea and swell.
- (7) Surface currents (including wind currents, mass transport by waves and permanent flow).

The whole task of thermal structure analysis and prediction is divided into nine programs, each with a number of subroutines:

- (1) Sea surface temperature program.
- (2) Sea and swell program.
- (3) Surface currents program.
- (4) Surface air temperature and water vapor pressure program.
- (5) Heat exchange program.
- (6) Mixed layer depth program.
- (7) Thermal structure program.
- (8) Transient thermocline program.
- (9) Ocean - atmosphere feedback program.

The first three are in operation and described elsewhere. General outlines are given below for programs 4 to 8. Program 9, which is in a research stage, will be described at a later stage, as will other oceanographic programs such as ice forecasting and forecasts for amphibious operations, which is illustrated in Figure 3.

2.1. Sea surface temperature (SST).

Sea surface temperature analysis has been described in:
P.M. Wolff, Operational analyses and forecasting of ocean temperature

structure. FNWF, June 1964.

The forecasting of SST is done by computing the local heat exchange (see 2.9.) and heat advection by currents (see 2.3.).

The verification of SST is direct, as synoptic observations of this element are made in connection with met. obs. over the oceans.

2.2 Sea and swell.

Sea and swell analysis and forecasting is described in: W.E. Hubert, Operational forecasts of sea and swell. FNWF, June 1964.

Forecasting is based on forecast wind fields and in case of swell also on previous wave fields. Verification is also direct. However, due to the rather inaccurate method of observation, verification is carried on mainly with more reliable weather ship observations.

2.3. Prognostic surface currents.

2.3.1. Surface currents.

The analyses and forecasting of surface currents is described in: W.E. Hubert, Computer produced synoptic analyses of surface currents and their application for navigation. FNWF, December 1964.

The verification of surface currents is indirect, using SST analyses. The change of temperature in 24 hours is computed at every grid point. From the computed change (difference) the computed local heat exchange is subtracted. The rest of the change is assumed to be due to advection (and mixing by heavy seas, if this is apparent). Using the SST gradient, the strength of the surface current can be computed.

2.3.2 Divergence and convergence.

The divergence/convergence is computed with the following formula, which neglects the effects of evaporation-precipitation and change of density.

$$-\frac{\partial v_z}{\partial z} = \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y}$$

In actual computations it is possible to compute the divergence or convergence in terms of the change of thermocline depth, using u and

v components of the currents (I).

$$\Delta D = (u_1 + u_3 - u_4 - u_2 + v_1 + v_2 - v_3 - v_4) D/4L$$

where D is mixed layer depth and L is the distance between grid points. This value is added to every grid point as these are used 4 times in computations (except the points near boundaries). This procedure causes some smoothing.

Near the coasts the first grid points on the land are used for divergence/convergence computations. However the results are divided by 2L (instead of 4L) and the results added to the points over sea areas.

The control of convergence is described in the MLD program.

2.4 Mixed layer depth(MLD),

The thermocline depth, caused by forced mixing by wave action, is computed from the highest sea and swell at any given point during the past 6 days.

$$D_w = K_1 H_w + K_2 H_s$$

H_w and H_s are sea and swell heights respectively; K_1 and K_2 are constants (II) (being evaluated).

To the MLD, found above, the thermocline depth change caused by convergence or divergence is added or subtracted.

The convergence needs to be controlled (see III). This can best be done with time; i.e., to keep the sum of convergence for 6 days, dropping the last day when the new one is added.

The convective stirring can be computed from the total heat exchange. Before this program is ready, convective stirring will be computed from the change of sea surface temperature, using the following formula:

$$\Delta T = \frac{D_d \Delta T_s}{T_{si} - T_d}$$

where D_d is the thickness of the thermocline (from upper boundary to

a lower, somewhat arbitrary boundary); ΔT_s is the change of sea surface temperature in 24 hours; T_{sl} is the previous sea surface temperature and T_d is the temperature below the thermocline (IV).

For addition of actual BT observations, the following procedure is recommended:

(1) Take the depth, where the temperature is 2°F ($\approx 1^\circ\text{C}$) different from that at the surface, as the depth of the thermocline. Compare the depth with mixed layer depth as computed with forced mixing, divergence/convergence, and convective stirring at the closest grid point, by subtraction. If the difference is $< \pm 12$ feet (ca. 4m), do not change the value of MLD, arrived at through the steps above (V).

(2) If the difference is > 12 feet, subtract 12 feet from this difference and add the rest to the neighboring 4 points in proportion to the distance (or according to the Carstensen scheme used for SST analyses).

(3) Keep the reports six days in the analysis scheme (VI).

The 48-hour forecast can be computed the same way as outlined above, using the forecast winds. The SST changes are predicted from total heat exchange.

The verification of mixed layer depth forecasts is done by BT reports, especially in cases and areas of surveys and naval exercises, and in areas of their scarcity, with the hydroclime data.

2.5 Subsurface thermal structure.

Take the MLD from program 2.4. and compute the temperature difference between SST and the hydroclime temperature at the next lowest "standard" level (VII). Compute also the hydroclime temperature difference between this and the next standard level. If the last temperature difference is $> 3^\circ\text{F}$ (1.5°C), add this difference to the above-found first difference (VIII).

Sum the differences between MLD and the lowest level depth used for above computation and give as D_d (needed in previous program 2.4.).

Sum the temperature differences and compute the temperature gradient in thermocline as $^\circ\text{C}/10\text{m}$ (or $^\circ\text{F}/30$ feet).

Take the hydroclime temperature at the lowest level used for gradient computation above and form the difference $T_{sl} - T_d$ (required for previous program 2.4.).

Print the temperature charts for standard levels by taking the SST if the thermocline is deeper than the given standard level; if not, take the time interpolated hydroclime temperatures (IX).

2.6. Transient thermoclines (X).

Compute MLD daily as caused by waves (2.3.) and compute the temperature change of this layer as caused by total heat exchange, assuming the additional heat is equally distributed within this mixed layer.

Subtract this change of temperature per 24 hours (caused by heat exchange) from the linearly interpolated 24 hour change of climatological sea surface temperature and map the positive values (XI) (XII).

Verifications of 2.5. and 2.6. are done with BT reports.

2.7. Surface air temperature and water vapor pressure analyses and forecast (including visibility and fog probability).

2.7.1. Surface air temperature.

Using synoptic reports, prepare the surface temperature analyses, using programs similar to SST analyses but using only 6 hourly synoptic values (XIII).

Compute the gradient of sea surface temperature at every grid point. Use these gradients and the u and v components of geostrophic wind and compute the change of air temperature over the sea for the next 6 hours with the following formula (by adding the changes in x, y directions):

$$T_w - T_a = (T_o - T_{ao}) e^{-kt} + \left(\frac{c}{k} + \frac{1}{k} V_r \frac{\partial T_w}{\partial r} \right) (1 - e^{-kt})$$

where $c = 0.1$ and $k = 0.12$; T_w is sea surface temperature at the location along wind (component) trajectory (computed from the rate of change of SST and wind speed); T_a is corresponding air temperature (XIV).

Compute $T_w - T_a$ at every grid point. This difference will be used for computation of Q_h (sensible heat exchange).

2.7.2. Water vapot pressure of the air.

Convert the dew point temperature into water vapor pressure (mb)

$$\log_{10} e_a = 9.405 - \frac{2353}{T}$$

Compute the saturation water vapor pressure of the sea surface, using the same formula as above but multiplying the results with 0.98.

Compute the difference $e_w - e_a$, which will be used for computation of the transfer of latent heat.

Compute $\frac{e_a}{e_w}$. Map the values above 0.9 with an interval of

0.02. These relative humidity values can be used for estimation of low visibility and fog probability. The humidity values will also be used in the computation of effective (long wave) back radiation.

Compute the change (forecast) of e_a with the same formulas and approach as used in 2.7.1. (replacing T_a with e_a and T_w with e_w) but using the following constants: $c = 0.18$, $k = 0.15$.

Compute the same quantities with forecast values as outlined in 2.7.2.

Direct verification with met. obs. is available.

2.8. Sea - air heat exchange (24 hours).

Compute Q_h (sensible heat exchange) using averaged scalar geostrophic wind speed and averaged $T_w - T_a$ for 24 hours (XV).

If $T_w - T_a$ is positive:

$$Q_h = 39 (0.26 + 0.077V) (T_w - T_a)$$

If $T_w - T_a$ is negative:

$$Q_h = 3V (T_w - T_a)$$

Compute Q_e (latent heat exchange) the same way.

If $e_w - e_a$ is positive:

$$Q_e = (0.26 + 0.077V) (e_w - e_a) L_h$$

If $e_w - e_a$ is negative:

$$Q_e = 0.077V (e_w - e_a) L_h$$

Sum Q_h and Q_e to form "sea-air heat exchange".

2.9. Total heat exchange (24 hours).

Compute the insolation for 24 hours using noon altitude of the sun and length of the day

$$Q_{os} = 0.014 A_n t_d$$

Compute the noon altitude of the sun with the formula:

$$\sin a = \sin \phi \sin \delta + \cos \phi \cos \delta \cos h$$

- a - altitude of the sun
- ϕ - latitude
- δ - declination of the sun
- h - hour angle

Compute the length of the day with the following formula:

$$\tan \phi \tan \delta = - \cos H_1/2$$

(H must be multiplied by 2 to obtain length of the day)
H - sun's hour angle

Compute the insolation as affected by clouds with the following formula (XVI):

$$Q_s = Q_{os} (1 - 0.0006C^3)$$

Compute the reflected radiation with the formula (XVII):

$$Q_r = 0.15Q_s - (0.01Q_s)^2$$

Compute the effective back radiation:

$$Q_{ob} = 297 - 1.86T_w - 0.95U_o$$

$$Q_b = Q_{ob} (1 - 0.0765C)$$

Compute total heat exchange:

$$Q_t = Q_s - Q_r - Q_b - Q_h - Q_e$$

3. Explanatory Notes.

- I This approach assumes the current between the surface and mixed layer depth.
- II The mixing by wave action is caused by turbulence, which can be empirically related to the orbital motion of water particles, which is a function (with depth) of wave height and length. The wave mixing is also a result of the simultaneous presence of a number of different waves. No satisfactory applicable theory exists for quantitative computation of this mixing, and empirical approaches will yield more plausible results. Considering the theories of orbital motion, the wave length is of considerable importance. It is suggested to overcome this by using both sea and swell data, whereby the factor K_2 would be considerably greater than K_1 by the same height (being evaluated), although theoretically swell would add little to mixing.
- III The convergence could be controlled on a small-scale chart (50 miles or less between grid points) with the maximum slope of interface (thermocline) derived from Margules's equation

$$i = \frac{W}{K(\rho_1 - \rho_2) D}$$

where ρ_1 and ρ_2 are derived from σ as inverse value.

Another possibility to control convergence is to assign some maximum values for MLD at given grid points. However this approach would be greatly misleading, as the thermocline slope is adjusted by dynamic factors (currents), convective stirring, possibly atmospheric pressure, etc.

As divergence and convergence are relatively slow processes, the best way to control convergence is with time, as suggested in 2.4. Divergence is controlled with forced mixing and convective stirring.

- IV The quantities D_d and T_d will be derived from thermal structure analyses; T_s and T_{sl} are available from sea surface temperature analyses.
- V The value ± 12 feet is derived from Mazeika's work and gives approximately the highest frequency of thermocline depth fluctuations. When time allows, later, this value may be changed and specified by season and location.
- VI This is a very tentative suggestion and would probably be changed according to experiences gained in verification.
- VII As "standard" levels are considered the following: 0m, 30m (100 feet), 65 (200), 100 (300), 150 (450), 200 (600), 400, 600 and 1000m.
- VIII The hydroclime temperatures at standard levels should be interpolated for every day down to 200m (600 feet), i.e., adding $1/30$ of the difference between actual and following month.
- IX The few BT's available and the way of reporting BT observations do not allow the extensive use of BT reports in this program. However, if we have agreed on our standard levels, we can request the extracting and reporting of temperature values at these levels.
- X Although some of the approximate methods have been discussed and could be used for prediction of transient thermoclines, their accuracy might be relatively low. The transients can best be predicted using total heat-exchange values.
- XI The increase of the mapped values indicates, indirectly, the probability of occurrence of transients.
- XII The same approach might be used by use of SST analysis (and rate of change computed from it) and the climatological interpolated rate of change. This approach by use of SST would, however, not allow any prediction.

- XIII This chart could be prepared both for land and sea areas. As the data density over sea areas is low, the forecast values (derived in 2.7.) could also be retained over sea areas in this analysis.
- XIV The numerical values for the constants k and c are rather arbitrarily selected between those of Bøyum and Laevastu. These can be later adjusted, if necessary.
- XV It might be necessary to adjust the wind factor to the geostrophic wind later, as the formulas have used surface wind earlier.
- XVI As Captain Wolff's cloud model contains three cloud layers, this formula will be changed accordingly, taking into account Haurwich and Lumb's data.
- XVII This formula is more accurate than a simpler one often in use
($Q_r = KQ_s$).

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SCHEME OF NUMERICAL ANALYSES AND PREDICTION OF OCEANOGRAPHIC ELEMENTS AND PROCESSES

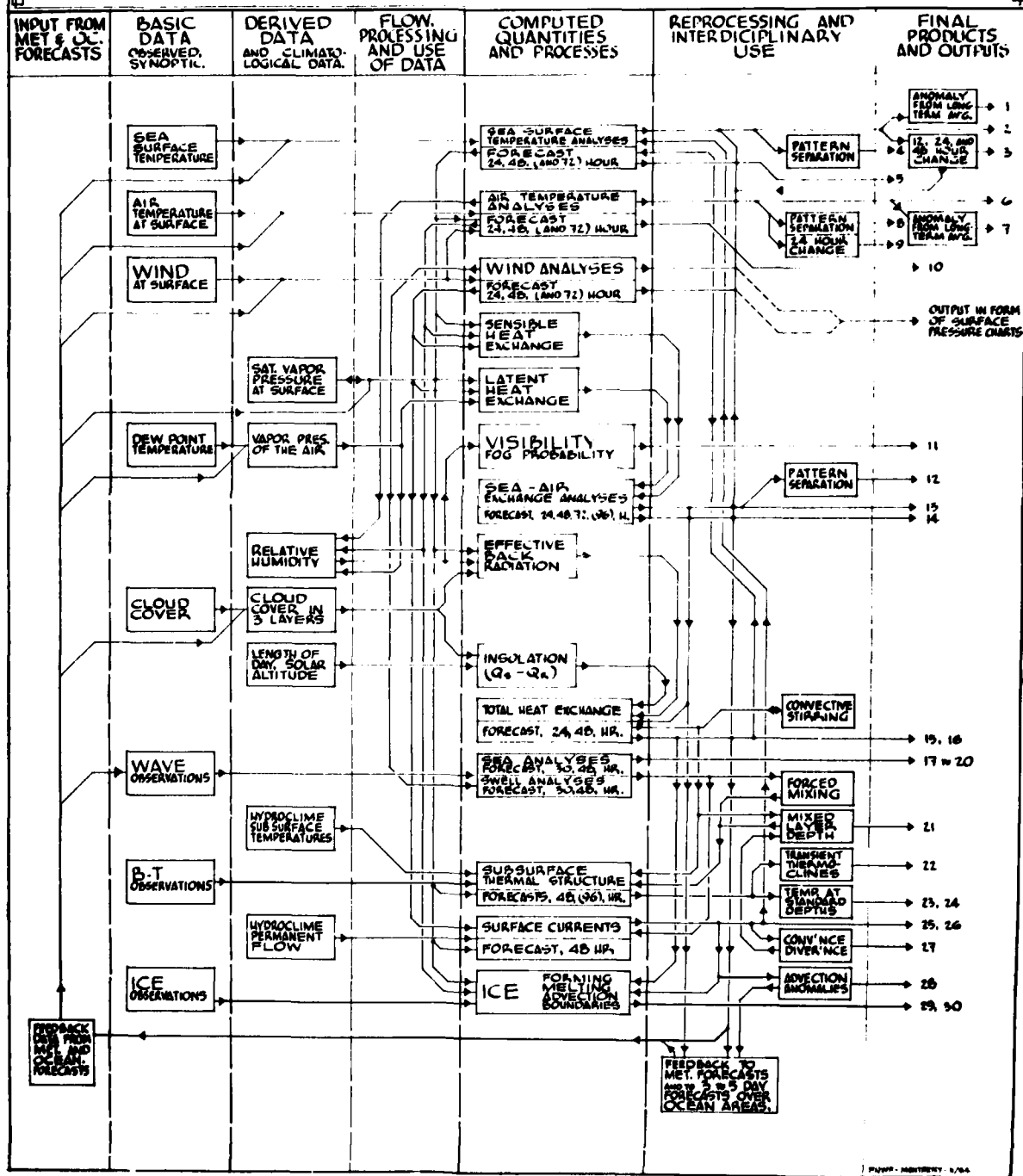
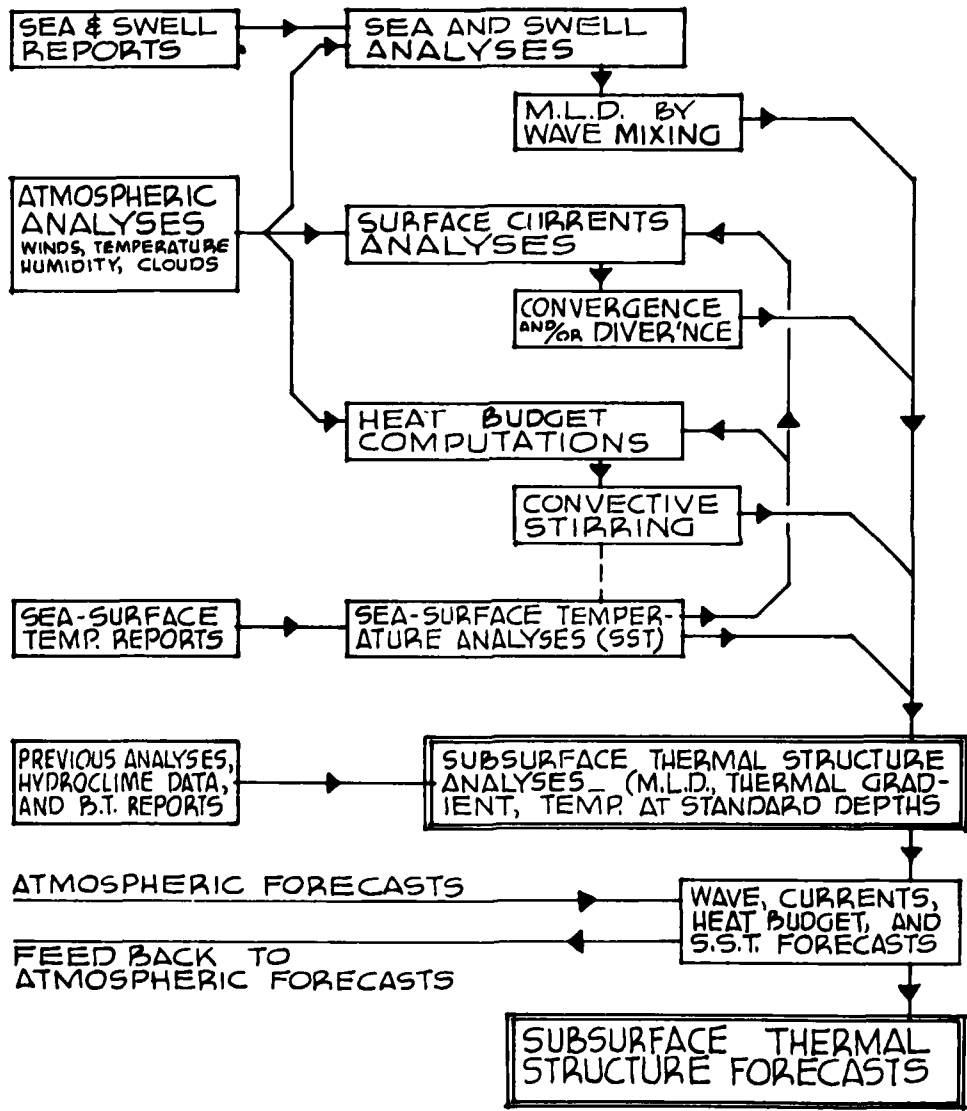


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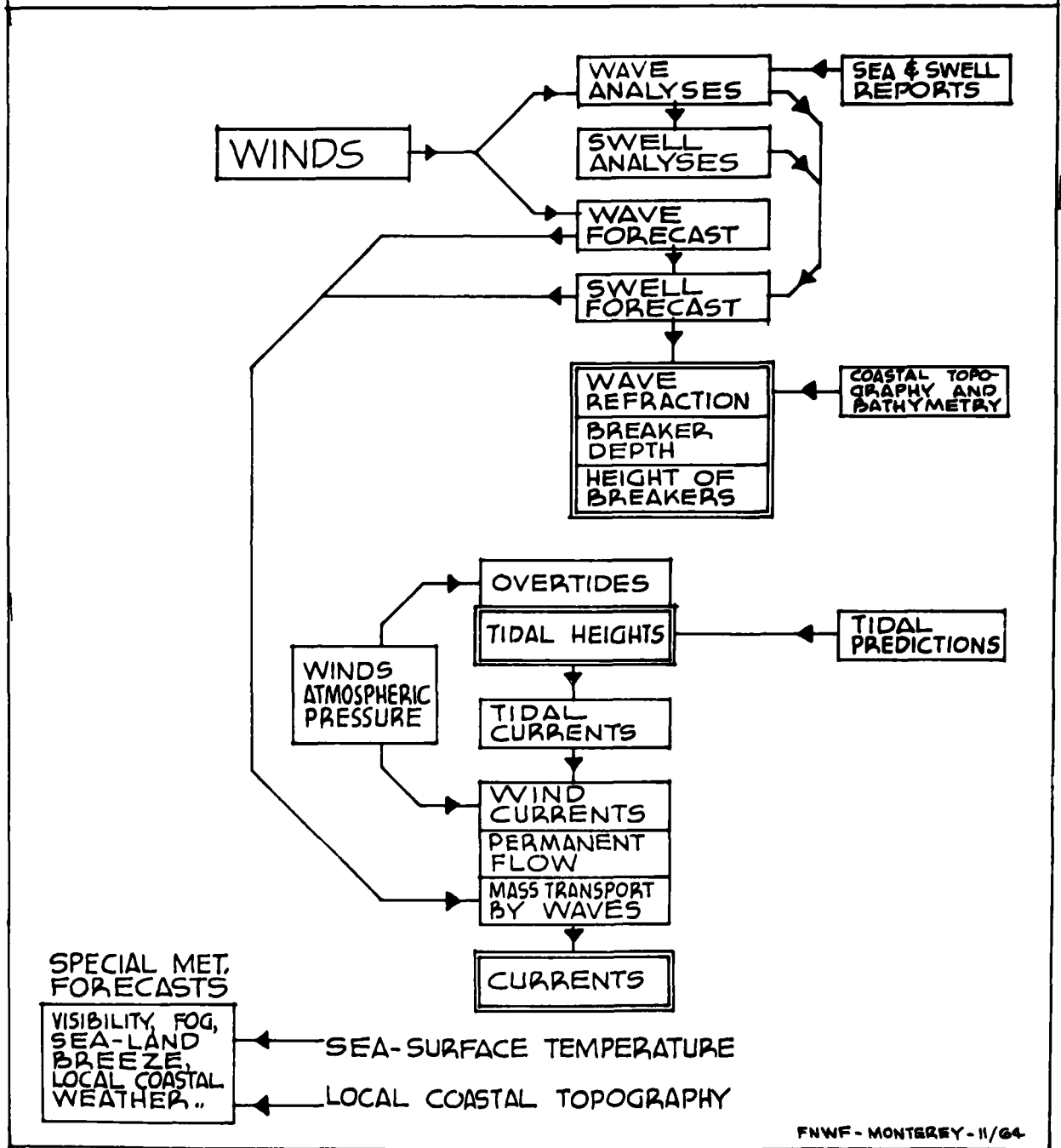
SCHEME FOR SUBSURFACE THERMAL STRUCTURE ANALYSES AND FORECASTING



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Figure 2

SCHEME OF OCEANOGRAPHIC ANALYSES AND PREDICTIONS FOR AMPHIBIOUS OPERATIONS



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Figure 3