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OPERATIONAL USES OF MICROMETEOROLOGY FOR SHIPS AT SEA,(U)
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OPERATIONAL USES OF MICROMETEOROLOGY FOR SHIPS AT SEA

PRODUCED BY THE
NAVAL WEATHER SERVICE ENVIRONMENTAL DETACHMENT, ASHEVILLE, N.C.

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(6)

OPERATIONAL USES OF MICROMETEOROLOGY FOR SHIPS AT SEA

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FORWARD

A great many simplifications and generalizations have been presented in this publication for the sole purpose of providing the military commander at sea a means of categorizing a portion of the environmental sphere as it pertains to his operating situation. The author does this in the interest of brevity and simplicity. For a fuller and more detailed understanding of this field the reader is referred to the following texts:

O. G. Sutton,	*Micro-meteorology*
R. Geiger,	*Climate Near the Ground*
F. Pasquill,	*Atmospheric Diffusion*
D. H. Slade,	*Meteorology and Atomic Energy*

The author is grateful for the assistance and technical review provided by the Naval Weapons Laboratory, Dahlgren, Virginia, in particular Mr. Robert Fenn. The author also wishes to thank staff members of the National Climatic Center for their helpful comments concerning this publication; Mrs. Arlee Banks for typing the manuscript; and Mr. Robert Ford for preparing the graphics.

OPERATIONAL USES OF MICROMETEOROLOGY FOR SHIPS AT SEA

1. INTRODUCTION

The movement (speed and direction) and diffusion of small particles or droplets depends on the atmospheric environment in various ways and to varying degrees.

The knowledge of these environmental factors and the ability to forecast the effects of these factors provides a military commander a means to use the environment to his advantage.

Persistence studies of wind, direction and speed, stability, and relative humidity permit probability forecasts for the movement and diffusion of particles in the atmosphere. These forecasts can be used in defensive or offensive operations.

2. MICROMETEOROLOGY ELEMENTS AFFECTING DIFFUSION

Micrometeorology is generally concerned with the atmospheric conditions within a few hundred feet of the earth's surface. For this publication micrometeorology is defined as that portion of meteorology that deals with the observation and explanation of the small scale physical and dynamic occurrences within the surface to 900 foot layer and horizontally, a cross section 10 miles wide. The most important elements affecting diffusion are:

(a) *Surface Wind - the wind direction and wind speed near the surface*

(b) *Low-level Wind - the wind speed and direction within a few hundred feet of the surface*

(c) *Air Temperature - ambient air temperature near the surface*

(d) *Sea Surface Temperature - the water temperature of the surface layer* *(e) Temperature Gradient - the temperature difference between the surface and a few hundred feet above the surface (low-level lapse rate)*

This list forms a basis for a micrometeorological forecast. Some situation may require consideration of fewer than all these elements. Those elements not directly considered would be included in the analysis process of making a forecast. The factors which control and influence the micrometeorological elements and the nature of their effects are discussed in the following section.

3. CONTROLLING INFLUENCES ON MICROMETEOROLOGICAL ELEMENTS

Surface wind, temperature, humidity and temperature gradients affecting the diffusion of small particles are controlled primarily by the synoptic (large scale) patterns of pressure, wind, humidity, and temperature and further modified by the local influences of the sea surface.

The characteristic behavior of each micrometeorological weather element in relation to the synoptic situation is discussed below.

3.1 Surface Wind Speed and Direction

Wind direction determines the direction of travel once small particles are emitted into the air. This is one of the most important micrometeorological element affecting diffusion. Wind speed primarily determines the rate of diffusion. Therefore, diffusion is least when the wind is calm. The variability in the speed and direction of the surface wind determines the lateral spread of a gas or aerosol cloud. This lateral spread is greatest when the wind is gusty and is shifting rapidly; it then amounts to about 50 percent of the distance traveled for distances of from one up to a few miles. With steady winds the lateral spread is only about 15 percent of the distance traveled, and under average conditions the lateral spread is about 20 percent. At distances greater than a few miles from release point the percent of the lateral spread is less than 15 percent. The vertical rate of diffusion is primarily a function of the low-level lapse rate (stability). The rate of diffusion in the vertical is relatively rapid and very erratic when the low-level lapse rate is unstable. The rate of vertical diffusion decreases with increasing stability of the low-level layer of air. The low-level lapse rate may be unstable immediately above the surface with a stable layer above. These conditions of low-level stability would promote rapid vertical diffusion through the unstable layer and very slow diffusion through the stable layer. Examples of changes in the rate of diffusion with different wind speeds are shown in section 5.

3.1.1 Effects of Synoptic Situation on Surface Wind

The air flow in the Northern Hemisphere near the earth's surface is counter-clockwise around low pressure with a cross isobar flow toward lower pressure. This cross isobar flow varies with the roughness of the surface. The rougher the surface the greater the cross isobar flow. The surface wind direction inflow over water is about 15° to the left (toward lower pressure) of being parallel to the isobars.

Surface wind speed at sea shows very little diurnal variation. There is remarkable steadiness in both the direction and speed of the surface wind at sea.

A knowledge of the current synoptic weather patterns affecting the ship's area of operation will provide a guide to major changes in wind direction. When the pressure gradient and fronts are weak and poorly defined, surface winds are subject to somewhat erratic behavior at low wind speed.

When underway, the apparent direction and speed of the wind usually varies from the true direction and speed. The apparent wind speed and direction is a resultant of the true wind speed and the ship's course and speed. Methods of determining the true wind direction and speed at sea are contained in NAVWEASERVCOMINST 3144.1, Manual for Ship's Surface Weather Observations.

3.1.2 Thermal Effects on Surface Winds

Water surfaces show small diurnal temperature variation and thus tend to reduce the normal diurnal variation of air temperature. Over the open ocean there is little diurnal variation in the wind. Warm air moving over cold water may result in a reduction of surface wind speed whereas cold air moving over a relatively warm water surface would have little effect on the surface wind speed. Coastal areas and enclosed seas, such as the Mediterranean, show marked diurnal changes in wind speed which may be noted up to 100 miles from the coast.

Sea and land breeze effects are thermally induced and are found in all coastal areas. Daytime warming of the land surface causes pressure to fall over the land and the cooler heavier air from the sea moves inland in a "sea breeze." At night the effects and the circulation reverse to produce a "land breeze."

Land/sea breezes occur almost daily in tropical and mid-latitude regions, on all coasts. They are strongest during the warm dry seasons and on clear days with a weak pressure gradient. They are usually evident during all seasons and even during cloudy weather, particularly in the tropics. A snow cover in coastal areas (in mid-latitudes) may inhibit sea breeze formation but a land breeze will form on clear calm nights.

Sea breezes are deeper and stronger than land breezes. They usually begin 2 to 4 hours after sunrise and subside between 2 hours before and 2 hours after sunset. They begin in a direction normal to the coastline then tend to rotate slowly in a clockwise direction until they are about parallel to the coast when they die away.

Sea breezes slowly increase in speed from their onset and reach a maximum in the afternoon, usually about 1 hour after the maximum land temperature is reached. A secondary maximum is sometimes reached about sunset. Maximum speeds are found a few hundred feet above the surface. Average speeds at the surface are from 10 to 15 knots. Sea breezes usually extend to a height of from 500 feet on medium sized lakes up to 5000 feet in tropical coastal regions. On very large islands, the movement of air is quite appreciable even at 12 to 15 miles inland. A sea breeze does not usually become turbulent or unstable until it has passed over a beach for some distance. With clear skies, sea air becomes turbulent after passing over approximately 500 yards of sunheated mainland or over an off-shore bar or island or other windward coastal strip. The sea breeze effect is noted 15 or more miles out to sea. Sea breezes are nonturbulent when they reach shore, but may become progressively more turbulent over land.

Land breezes are considerably weaker and shallower than sea breezes; they are usually less than 500 feet thick and start about an hour after sunset, ending shortly after sunrise. Land breezes usually extend only 5 to 6 miles out to sea. Because they form over land, land breezes are more turbulent in nature but the turbulence may be damped by nighttime inversion conditions.

Both land and sea breezes are influenced by the direction and velocity of the gradient wind. Increasing gradient winds delay the development of land and sea breezes and weaken or distort the system, appreciably affecting maximum speeds.

With little or no surface wind (0 to 5 knots), the sea breeze develops normally. A synoptic wind of 5 to 10 knots from the land toward the sea delays the sea breeze until late morning or midday; a synoptic wind of 10 to 14 knots delays the sea breeze regime until mid-afternoon. Under these conditions the sea breeze starts several miles out to sea and slowly progresses shoreward, arriving on land as a gusty, sharp wind shift. Synoptic winds of 15 knots or more greatly distort all but the strongest sea breezes. The land and sea breeze are vectorially added to the synoptic wind; a daytime shoreward synoptic wind strengthens the sea breeze, and nighttime shoreward gradient wind weakens the land breeze as shown by the following figures.

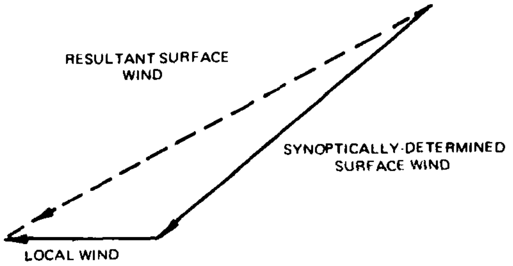

FIGURE 3.1 VECTORIALLY-ADDITIVE WIND VELOCITIES

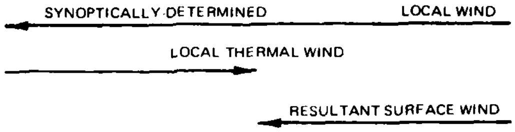

FIGURE 3.2 WIND VELOCITY RESULTING FROM OPPOSING WINDS

3.2 Low-level Mean Wind Speeds

Ordinarily, winds increase with height at these low-levels. Normally, then, the mean surface to 100 foot wind speed will be greater than the surface wind speed and the mean surface to 500 foot wind speed will be greater than the surface to 100 foot wind speed.

The increase in wind with height is usually greatest during very stable conditions (inversion) and least during unstable conditions. The wind direction generally changes in a clockwise manner (veering) with increasing height. A rough approximation for the change of wind direction from the surface to 1500 foot level would be 1 degree per 100 feet increase of altitude.

Figure 3.3 depicts the ratio of low-level mean wind speeds (surface-900 feet) to the observed surface wind speeds with respect to low-level stability. Low-level stability can be estimated from the air-sea temperature difference in the absence of more direct information.

An air-sea temperature difference less than -2.7°F would be an indicator of an unstable low-level layer of air, or if the difference were greater than +1.8° the low level layer of air would be considered stable. An air-sea temperature difference between -2.7°F and +1.8°F would be considered an indicator of near neutral stability of the low-level layer of air.

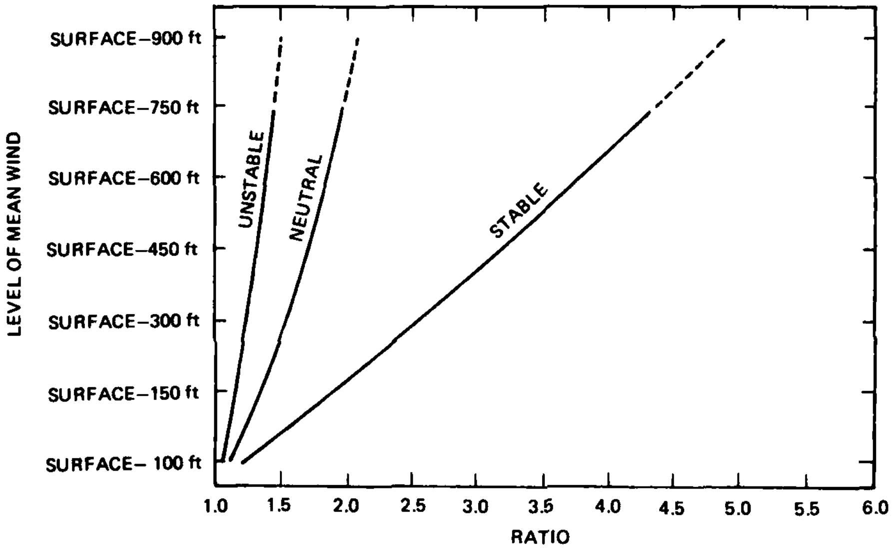

FIGURE 3.3 RATIOS OF MEAN WIND SPEEDS TO OBSERVED SURFACE WIND SPEEDS

Once the stability of the low-level layer of air has been determined or estimated the mean wind speed over the desired interval (e.g. surface-300 feet) is computed using the ratio from Figure 3.3.

> *Example: The mean wind speed for the level surface-300 feet (the low-level air layer is neutrally stable) would be obtained by multiplying a ratio of 1.5 times the observed surface wind speed.*

3.3 Air Temperature

(a) Time of Day

Temperature generally has a pronounced diurnal trend with the low occurring just about dawn, and the high about 1 to 2 hours after noon (LST). The diurnal air temperature range at sea is slightly greater than the sea surface temperature range. The sea surface temperature varies over a smaller range than the air temperature as shown by the following figure.

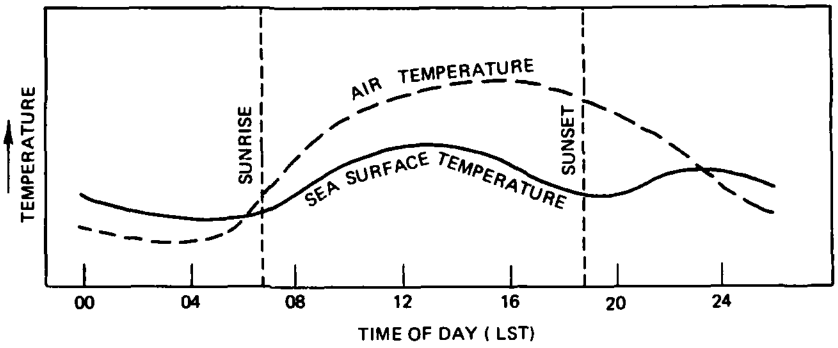

FIGURE 3.4 DIURNAL AIR AND SEA SURFACE TEMPERATURE VARIATION

(b) Cloudiness

Maximum temperature changes occur with clear skies as cloudiness has a modifying effect on the diurnal temperature cycle. The lower and denser the clouds the less variation in the diurnal temperature. Cloud factors to be considered are: degree of cloudiness, cloud type, and cloud height. High scattered clouds (Cs and Ci) restrict outward radiation by only a few percent and allow a near normal (clear sky) diurnal temperature regime to occur. Low overcast reduces outward radiation by approximately 90 percent and diurnal temperature variation is greatly reduced or eliminated.

(c) Horizontal Advection

Synoptic movement of air containing marked horizontal temperature gradients (as in the case of fronts or thermally contrasting air masses) can mask the normal diurnal and radiation effects; in mid and polar latitudes, particularly in winter, this can dominate temperature control. Air temperatures are then forecast by estimating the temperature of the air that will be advected into the area, with appropriate modifications due to radiation and local effects.

(d) Vertical Mixing

Strong pressure gradients and other wind-producing mechanisms tend to keep the lower atmosphere well mixed up to a height of several hundred to a few thousand feet. This mechanical mixing produces a more uniform air temperature (reducing the maximum and raising the minimum temperature).

3.4 Sea Surface Temperature

Water absorbs radiation through a deep layer. Because water has a high specific heat its temperature changes are slow and small as a result of incident radiation. The normal diurnal variation of temperature over water is considerably less than over land. Daytime maxima are reduced and nighttime minima are raised by 5 to 10 degrees, depending on the depth, extent, and normal relative temperatures of the water surface. The diurnal range of ocean surface water temperature is normally 2°F; the diurnal range of air temperature over the water is only slightly greater than this, unless affected by a nearby land mass. Over tropical oceans the air temperature is normally a fraction of a degree lower than the ocean surface temperature.

Since the variation of sea surface temperature would be quite small during an operation at sea the determination of the sea water temperature is very important. One common method of determining sea surface temperature utilizes a bucket in which a sample of sea water is obtained. A standard air thermometer is immersed and read after several minutes of immersion. Another common method in use obtains the sea water temperature from the main condenser injection thermometer. Since the condenser sea water intake is below the water line this second method will yield temperatures slightly cooler than the former method.

3.5 The Temperature Gradient

The vertical temperature gradient is a measure of the atmospheric stability and this is a partial measure of the diffusive characteristics of a layer of air. During the day direct sunlight heats the air above the surface of the water more rapidly than the water. In contrast the ground is heated by direct sunlight to temperatures that are considerably higher than the air above the ground. This produces a very unstable shallow layer of air (e.g. surface to 10 feet). Since the low-level temperature gradient over water does not exhibit the extremes found over land a thicker layer (e.g. surface to 300 feet) has been selected to represent the stability at sea.

The low-level atmospheric stability at sea can be estimated from the air-sea temperature difference. This provides a useful measure of diffusity at sea in the absence of an upper air sounding. For most operations at sea three categories of stability (unstable, neutral and stable) are sufficient.

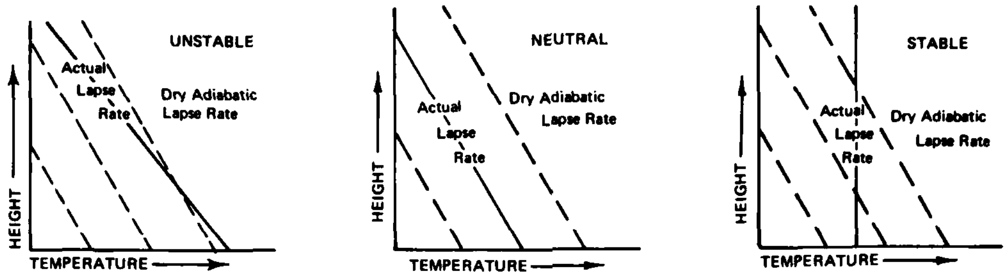

FIGURE 3.5 THREE CATEGORIES OF ATMOSPHERIC STABILITY

An unstable layer of air is one in which the lapse rate is greater than the dry adiabatic lapse rate. If a parcel of air were displaced upward it would cool at a slower rate than the environmental lapse rate; therefore, it would be warmer than the surrounding air temperature and continue moving farther from its original position. Under these conditions diffusity is high.

Neutral stability describes an atmospheric condition where a parcel of air may be displaced upward and the temperature of parcel changes at a rate that is approximately the same as the surrounding air. Once the initial displacement has stopped the parcel tends to stay at the new level. Under this atmospheric condition, small particles or droplets released from a source that is warmer than the surrounding air temperature would be displaced upward until it cools to equal the surrounding air temperature. The diffusity would be described as moderate.

A stable layer of air, when displaced upward would cool at a rate whereby it would be colder than the surrounding air and therefore denser. The parcel would sink back to its original level. The diffusity would be described as slight.

3.5.1 Effect of Synoptic Situation on Temperature Gradient

Increasing surface wind speeds cause inversions to weaken; winds over 10-15 knots generally destroy inversions and create a neutral lapse rate. Precipitation also inhibits the formation of both very stable and very unstable conditions. When fog is present, slightly stable conditions are most probable.

The stability of the air in upper layers does not always indicate the temperature gradient in the lower layers. Therefore it is not possible to predict the lapse rate in the lower layer from upper air stability.

3.5.2 Effects of Surface Characteristics on Temperature Gradient

At sea there is almost no diurnal variation of temperature gradient. Turbulence and stability of the lower layer depend on the temperature difference between the air and water. Because the sea surface temperature is fairly constant, stability is largely determined by the degree and kind of temperature advection in the air over the water surface. Warm air moving over colder water results in an increase in stability in the lower layer, while cold air moving over warm water results in increasing instability. If air travels over water for a few hours the lapse rate usually becomes neutral in the lowest 50 feet. Over tropical oceans a neutral stability condition almost always prevails. In shallow water, as in a lagoon, there is appreciable warming by the sun and unstable conditions may exist in the lower levels.

3.6 Relative Humidity

This effect is not likely to be of major importance in the range of conditions that will be encountered at sea in middle or lower latitudes. A relative humidity equal to or greater than 50 percent can normally be expected for most operating areas at sea.

4. MICROMETEOROLOGICAL FORECASTING

4.1 Information Required

The availability of meteorological information for a ship's operations could vary from a relatively complete synoptic observation from the ship alone to a total synoptic forecast for the operating area. Ideally, the surface wind, air temperature, sea temperature, temperature gradient, relative humidity, and low level mean wind speed would be observed and a forecast of these parameters would be provided for the required time period. Such observations are not often available for an operating area in advance; therefore, less direct sources of information must be used.

All of the following sources that are available should be consulted to obtain information for a micrometeorological forecast or estimate:

(a) Climatological data
(b) Synoptic maps (surface and upper air)
(c) Upper-air soundings
(d) Satellite pictures

If none of the above are available, use your current meteorological observation and turn to section 5.3.

(a) Climatological data for a specific area of interest could be obtained from the U.S. Navy Marine Climatic Atlas series. This series of eight atlases, is in the NAVAER 50-1C- series and begins with the North Atlantic Ocean NAVAER 50-1C-528. The following elements of a micrometeorological forecast are presented in each atlas.

Monthly percentage frequency of surface wind speed less than or equal to 10 knots.
Monthly percentage frequency of surface wind direction to 8 points of the compass.
Monthly mean air temperature (°F) which also includes mean sea surface temperature (°F) for representative areas.
Seasonal air-sea temperature difference (°F) and percentage frequency of surface based inversions.

In the event that the operational area is in a coastal zone the U.S. Naval Weather Service Command's Summary of Synoptic Meteorological Observations (SSMO) should be checked to see if the area has been summarized and is aboard. In the absence of other data for the specific area the atlas series would provide a guide for preparing a micrometeorological forecast. The normal range, mean conditions, and the probability of occurrence of a forecast value is available from the appropriate charts in the atlas. It can, in the complete absence of synoptic information, serve as a substitute for a forecast.

(b) <u>Synoptic surface maps</u> augment direct observations by providing the basic information for forecasting or estimating the micrometeorological conditions in an area of interest. In the event direct observations are not available, estimates of micrometeorological conditions can be made from the synoptic maps by interpolation. Synoptic map analyses are particularly valuable in estimating pressure gradient, wind and temperature at sea.

(c) <u>Upper air soundings</u> are useful in determining the vertical distributions of temperature, moisture and wind; these in turn are helpful in estimating cloudiness, low-level stability, surface winds, and low-level (surface to 300 feet) winds.

(d) Satellite data can supplement or substitute for synoptic maps in determining cloud patterns, storm locations and movement, and occasionally general wind fields. These in turn can be helpful in estimating the surface wind direction and air temperature.

4.2 Forecasting Procedures

The micrometeorological forecast can best be approached by first considering each element separately and then in conjunction with each other. The following sections outline general procedures for forecasting each micrometeorological element.

4.2.1 Forecasting the Surface Wind

Step 1 - Climatology

The first step in forecasting the surface wind is to become familiar with the climatology of the element in the region of interest. Consult the Marine Climatic Atlas series to familiarize yourself with the area of interest. Climatology will provide the averages, frequencies of occurrence, and limits of weather phenomena. The current meteorological observation from your own ship plus persistency and climatology will provide the basic information for micrometeorological predictions or estimates. Caution must be exercised in making the final forecast to insure that all the probabilities presented have been taken into consideration.

Step 2 - The Synoptic Situation

The direct observation of the surface wind can be determined in accordance with the Manual for Ship's Surface Weather Observations, NAVWEASERVCOMINST 3144.1. The surface wind may also be estimated from the synoptic pressure field of a surface weather analysis. Some of the weather plotting charts in use in the Naval Weather Service have geostrophic wind scales printed on them. The angle between the geostrophic wind and the actual wind varies with latitude, wind speed and curvature of the isobars. As a "rule of thumb" use 15° as the angle between the geostrophic and the actual wind at sea.

The following figure shows the relationship between the geostrophic wind and the actual wind.

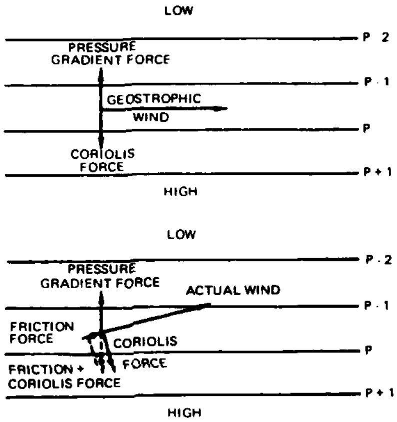

FIGURE 4.1 BALANCE OF FORCES

Geostrophic wind scales are either graphic or tabular solutions of the geostrophic wind equation. It must be remembered that these computations are made under the assumptions of: straight isobars and frictionless flow. The "rule of thumb" 15 degree difference is an average value that corrects for the curvature of the isobars and friction. The frictional drag of the sea surface on the atmosphere reduces the wind speed near the surface. This effect also adds to the cross isobar flow.

A geostrophic wind table is presented for use in determining wind speeds from synoptic charts.

TABLE 4.1

Wind speed observed (knots)	Approximate distance (in nautical miles) between isobars drawn for every 4 millibars			
	30°	40°	50°	60°
10	461	358	301	266
15	307	239	200	177
20	230	179	150	133
25	184	143	120	106
30	154	119	100	89
35	132	102	86	76
40	115	90	75	66
50	92	72	60	53
60	77	60	50	44

Geostrophic wind distance between isobars over ocean at 4-mb intervals for various wind speeds and latitudes.

When upper air observations are available from the operating area, they can be useful in determining the wind flow above the surface, the stability and the wind speeds at heights above the surface. An additional check on the low-level wind direction may occasionally be obtained from satellite pictures. If lower-level clouds are observed, their direction can sometimes be determined by the banding structure; that is, by the shape and arrangement of cumulus cells. The most recent publications on these rapidly evolving techniques should be consulted.

Step 3 - Final Climatological Check

The final step is to check the forecast for implausible or impossible situations. In using climatological data to check the general forecast, the probability of occurrence of the forecast values should be determined. When forecast values of surface wind, or any other micrometeorological element, are near climatological extremes the forecast should be reevaluated by a second analysis of the synoptic situation.

4.2.2 Forecasting Low-level Wind

The relationship of low-level mean wind speeds to the temperature gradient and synoptic wind speed was discussed in section 3.2. In the absence of direct measurement of mean winds, they can be estimated from the synoptic wind and stability predictions. The table below shows the expected ratios of surface-100 foot and surface-750 foot mean wind speeds to the synoptic wind speed.

TABLE 4.2

Stability	Surface-100 feet mean wind	Surface-750 feet mean wind
Unstable	1.0	1.4
Neutral	1.1	2.0
Stable	1.2	4.3

Ratios of Mean Wind Speeds to Synoptic Wind and Stability Conditions

To illustrate the use of this table; a synoptic wind of 10 knots under unstable conditions would indicate a surface-100 foot mean wind of 10 knots and a surface-750 foot mean wind of 14 knots, while under stable conditions the mean wind speeds would be a maximum of 12 and 43 knots, respectively.

4.2.3 Forecasting Air Temperature

Step 1 - Climatology

The first step in forecasting air temperature is to become familiar with the climatology of the element in the region of interest. Consult the Marine Climatic Atlas series to study your area of interest. Climatology will provide the averages, frequencies, and limits of weather phenomena. Where synoptic data are unreliable or missing, climatology will provide the basic information for micrometeorological predictions or estimates. Caution must be exercised in making the final forecast to insure that all the probabilities presented have been taken into consideration.

Step 2 - The Synoptic Situation

Consult available synoptic maps to ascertain the temperature fields, air masses, fronts, cloud patterns, wind and moisture fields that will be effecting the operating area.

Step 3 - Final Climatological Check

The final step is to check the forecast with climatology to determine the probability of occurrence of the forecast value, and then to reexamine any improbable predictions.

4.2.4 Forecasting Sea Surface Temperature

In the absence of direct observations, a sea surface temperature forecast must be based on climatology. Since sea water has a high specific heat it's temperature changes slowly making the sea surface temperature one of the most conservative elements of the micrometeorological forecast.

4.2.5 Forecasting the Vertical Temperature Gradient

When upper air observations are available from the operating area, they are the best means of determining the temperature gradient aloft (stability). In the absence of such observations a simplified procedure can be used to obtain a first approximation to the low-level stability. Using the predictors: (a) surface wind speed, (b) cloudiness, (c) air-sea temperature difference and (d) visibility, an estimate of the stability category is possible.

(a) Surface wind speeds greater than 10 knots generally prevent very stable (strong inversions) conditions from persisting. Likewise very unstable (superadiabatic) conditions will not persist when wind speeds are above 10 knots. Neutral stability is the most common condition with wind speeds greater than 10 knots.

(b) Stratus cloudiness (bases below 5000 feet) generally indicates stable or neutral conditions. Cumulus cloudiness indicates neutral or unstable conditions.

(c) The air above the surface of the water heats more rapidly during the day than the water and stable (inversion) conditions frequently result. At night the air cools more rapidly than the water. When the water becomes warmer than the air (i.e. the air-sea temperature difference becomes negative) by as much as 3 degrees or more, the low-level air becomes unstable.

(d) If the horizontal surface visibility is less than 7 miles and the restriction is due to haze, stable air is generally indicated. The air is probably neutrally stable if it is clear without haze.

4.2.6 The Final Forecast

A final procedure in making a micrometeorological forecast is to ascertain that each element is in agreement with the others and does not set up an impossible situation. Because each element is interdependent on the others, constant cross-checking and questioning is required: for instance, can the forecast temperature gradient exist with the forecast wind and sky cover?

The final forecast should be a carefully considered, integrated whole. It should weigh all the measurable and estimable effects of the environment, utilizing the available objective forecasting technology as well as the experience, skill, and judgment of the forecaster.

No single procedure will apply to all areas at sea or to every operational situation. In the sample problems in section 5, tables are designed to accommodate the particular forecasting problems.

5. OPERATIONAL USES

5.1 Mid-Ocean Area Sample Problems

A micrometeorological forecast is needed for an equatorial location in mid-ocean for 0400 local time, on 5 June. The ocean area is centered on 10°S latitude and 73°E longitude. The operational situation requires surface wind, surface-100 mean wind speed, air temperature, sea surface temperature and temperature gradient (unstable, neutral or stable category).

The following information is available:

Synoptic map series to 1200 GMT, 4 June
Prognostic charts for 0000 GMT, 5 June
Climatological data

(a) The Surface Wind Forecast

The following table is set up to provide orderly consideration of all factors affecting the surface wind.

TABLE 5.1

Environment Effects	Wind Speed (Knots)	Wind Direction
Climatology (June)	(mean) 12	SE
Synoptic Wind (1200 GMT, 4 June)	15	ESE
Forecast wind (prognostic chart 00GMT 5 June)	10	SE
Climatological probability	high	
Final micro-wind forecast	10	SE

Step 1 - Climatology

June is the beginning of the winter season at this latitude though the marine climate of this equatorial area has a high temperature throughout the year. There is very little seasonal variation. The driest months are during the winter with a monthly total precipitation of just over 5 inches. Surface winds are southeasterly over the area during the winter months. The southeasterly air flow is very persistent. Scattered to broken stratocumulus and cumulus cloudiness prevails over the area during the winter season. The following climatological table is presented for comparative purposes.

TABLE 5.2

Climatology	*May*	*June*	*July*
Mean wind speed (knots)	*15*	*15*	*15*
Prevailing wind direction	*SE*	*SE*	*SE*
Mean monthly air temperature (°F)	*81*	*79*	*77*
Mean monthly sea surface temp. (°F)	*81*	*80*	*78*
Air-sea temperature difference	*-1 to +1*	*-1 to +1*	*-1 to +1*
Percent frequency of total cloud cover 2/10 or less	*20*	*20*	*<20*
Percent frequency of observations with precipitation	*10*	*10*	*15*
Percent frequency of surface based inversions		*<5*	*seasonal*
Prevailing wind direction at 850 mb (5000 feet)		*ESE*	
Mean wind speed at 850 mb (knots)		*18*	

From sunrise and sunset tables for 5 June

Time of sunrise 0611 LST (0123 GMT)
Time of sunset 1745 LST (1257 GMT)

Step 2 - Synoptic Situation

The prognostic charts indicate scattered clouds (4/10) and a continuation of the prevailing southeasterly surface winds. The pressure gradient will continue to produce wind speeds of 10 to 15 knots. The air mass stability is probably neutral during daylight hours and becomes slightly unstable during the early morning, predawn hours. A few instability showers will be scattered over the area during the early morning hours.

Step 3 - Climatological Probability

As the climatological information indicates the SE, 10 knot wind to be an ordinary occurrence, there is no climatological reason to doubt its validity. A wind of SE, 10 knots is then entered as the final surface wind forecast.

(b) The Surface-100 Foot Mean Wind Forecast

The table in section 4.2.2 gives the relationships of mean wind speeds to the synoptic wind with stability conditions. As it has already been determined that a neutral stability or slightly unstable condition is most likely at 0400 LST with a synoptic wind speed of 10 knots, a surface-100 foot mean wind speed of 1.1 times the synoptic wind speed is computed. A surface-100 foot mean wind speed of 11 knots would be indicated.

This forecast surface-100 foot mean wind speed should be viewed from a practical point of view. Since the precision of the forecast wind is such that the actual wind will be within the speed envelope of 8 to 13 knots, an adjusted surface-100 foot mean wind speed of 14 knots appears more representative.

(c) The Air Temperature Forecast

Step 1 - Climatology

The mean maximum June temperature is 83°F, the mean minimum is 76°F. The temperature at 0400 LST would be about 77°F if the normal diurnal temperature variation is followed.

Step 2 - Synoptic Situation

Synoptic maps indicate the previous minima have ranged from 75 to 77 degrees. The scattered to broken cloudiness indicates that near normal temperature variations can be expected. There is no temperature advection in the synoptic wind field. Surface winds will continue to provide vertical mixing with the aid of a sea surface temperature that is slightly warmer than the air temperature. The forecast is for a 76°F, 0400 LST temperature.

Step 3 - Climatological Probability

The forecast is very close to normal, therefore there is a high probability of verification for this forecast.

(d) The Sea Surface Temperature Forecast

Since the sea surface temperature is the most conservative parameter of all those that are being considered for this problem, climatology will be the primary source for its forecast. During the early morning hours the sea surface temperature is generally warmer than the air temperature. Synoptic considerations have shown that no temperature advection is expected. The mean sea surface temperature for this area is 80°F. The forecast air temperature for 0400 was 76°F, therefore adjusting the sea surface temperature for a slight diurnal temperature variation a temperature of 78°F is forecast for 0400 LST.

(e) The Temperature Gradient (Stability) Forecast

As indicated in earlier sections, the time of day, air-sea temperature difference and wind speed can be used as predictors to estimate the category of low-level stability. A neutral to slightly unstable low-level atmosphere is indicated by using the predictors of: time of day (0400 LST), air-sea temperature difference (-2°F), and mean surface-100 foot wind speed (14 knots).

(f) The Final Forecast

As a result of the available information, the forecast requirements, and the forecast procedures, the final forecast for the mid-ocean area at 0400 LST, 5 June is as follows:

Surface wind - SE 10 knots
Air temperature - 76 degrees F
Temperature gradient - neutral
Low-level wind speed - 14 knots
Sea surface temperature-78 degrees F

Remarks: The diffusion of small particles would be described as moderate.

5.2 Tropical Coastal Area Sample Problems

A micrometeorological forecast is required for 1800 LST (1000 GMT), 15 August, for a coastal area that is centered on 20°N latitude, 108°E longitude. The operational situation requires surface wind, surface-750 foot mean wind speed, air temperature, sea surface temperature and temperature gradient (category).

The following information is available:

Synoptic map series to 0000 GMT, 15 August
Prognostic charts for 1200 GMT, 15 August
Satellite picture covering the area at 0213 GMT
Radiosonde data from a ship 45 miles south of the area
Summary of Synoptic Meteorological Observations (SSMO) for the Coastal Area
Climatological tables

(a) The Surface Wind Forecast

The following table is set up to provide orderly consideration of all factors affecting the surface wind.

TABLE 5.3

Environment Effects		Wind Speed (Knots)	Wind Direction
Climatology (August)	Mean	12	SE thru WSW
	Maximum	35	
Synoptic Wind (0000 GMT, 15 August)		10	S
Forecast Wind (Prognostic charts 1200 GMT 15 August)		15	SE
Climatological probability		Reasonably high	
Final micro-wind forecast		15	SE

Step 1 - Climatology

The Southwestern Monsoon is well established over the operating area by August. The intertropical convergence zone (ITCZ) is to the north but by September the ITCZ is starting to retreat southward. The summer is the wettest season. Cumulonimbus clouds are the primary source of precipitation during the summer months. Thunderstorms occur on an average of 10 days during August, late evening through early morning is the most frequent time period. The following climatological table is presented for comparative purposes.

TABLE 5.4

CLIMATOLOGY	JUL	AUG	SEP
Mean wind speed (knots)	12	10	10
Wind direction (percent frequency of occurrence)			
N	2	3	6
NNE	2	1	9
NE	1	1	14
ENE	1	2	13
E	4	5	6
ESE	3	6	4
SE	8	10	5
SSE	11	12	6
S	16	11	7
SSW	10	10	3
SW	6	10	4
WSW	9	9	3
W	13	7	5
WNW	6	5	4
NW	4	3	5
NNW	2	4	4
Mean air temperature (°F)	86	85	84
Mean sea surface temperature (°F)	86	86	85
Air-sea temperature difference (°F)	+1 to-1	-1 to-2	-1 to -2
Mean relative humidity (%)	79	79	78

Step 2 - Synoptic Situation

The synoptic analysis for 0000 GMT, 15 August (0800 LST) depicts broken to overcast clouds over the entire area with thunderstorms and rain showers. The local pressure pattern is somewhat ill defined but a major storm 500 miles to the ESE is beginning to influence the area weather. The prognostic charts for 1200 GMT, 15 August indicates continued broken to overcast clouds with an increase in showers and thunderstorms. Surface winds will be subject to local variations in the vicinity of thunderstorms. The prevailing direction will be southerly. The air mass will continue to be slightly unstable during the forecast period.

Step 3 - Climatological Probability

The presence of thunderstorms will decrease the probability of the wind direction verifying since thunderstorms tend to generate a local wind pattern. The wind speed would also be affected. The final surface wind forecast will remain SE, 15 knots with a qualification to expect local variations when thunderstorm activity is nearby.

(b) The Surface-750 Foot Mean Wind Forecast

The radiosonde observation from the ship 45 miles to the south indicates a 1000 foot wind speed of 10 knots. The synoptic wind speed obtained from the 0000 GMT surface analysis was S at 10 knots. Applying a surface-750 foot mean wind speed ratio of 1.4 to the synoptic wind speed of 10 knots yields a 14 knot mean wind speed for the layer. Under the conditions discussed in the synoptic situation this forecast appears reasonable.

(c) The Air Temperature Forecast

Step 1 - Climatology

The mean maximum August temperature is 95°F, the mean minimum is 76°F. The temperature at 1800 LST would be about 88°F if the normal diurnal temperature variation is followed.

Step 2 - Synoptic effects

There is sufficient cloudiness to reduce the normal diurnal curve of temperature. There is no advection of temperature indicated in the low-level flow during the forecast period. The radiosonde taken 45 miles south of the operating area indicates that vertical mixing will take place through the lower layer. A synoptic temperature of 85°F is forecast including a modification for cloudiness.

Step 3 - Climatological Probability

The forecast is very close to normal, therefore there is a high probability of verification for this forecast.

(d) The Sea Surface Temperature Forecast

The mean sea surface temperature for this area during the month of August is 86°F. Considering the diurnal temperature variation and modifications for cloudiness, a sea surface temperature forecast for 1800 LST will be 86°F.

(e) The Temperature Gradient Forecast

Previous sections of this publication have discussed the use of the various predictors to estimate the category of low-level stability. In addition, the radiosonde observation from a nearby ship provides a direct means to determine the stability fairly close to the operating area. A slightly unstable low-level layer is forecast based on the radiosonde observation. This is reasonable from climatology and synoptic considerations.

(f) The Final Forecast

The final forecast for the tropical coastal area at 1800 LST, 15 August is as follows:

Surface wind	*SE 15 knots*
Low-level wind speed	*14 knots*
Air temperature	*85 degrees F*
Sea surface temperature	*86 degrees F*
Temperature gradient	*slightly unstable*

Remarks: Scattered thunderstorms with locally higher wind speeds and direction varying from the forecast value should be expected. The diffusion of an aerosol would be described as "fairly rapid."

5.3 General Procedures

The preceding sample problems illustrate the methodology of categorizing the environmental conditions that are likely to confront the military commander at sea. A dynamic process such as turbulent diffusion can be categorized only by over simplifying the process. The stereotyping of the process was deemed necessary in the interest of operational expediency.

The stability of the low-level layer of air can be estimated using the following air-sea temperature difference vs wind speed table:

TABLE 5.5

Air-Sea Temperature Difference (°F)

Wind Speed (Knots)	*<*	*-3*	*-2*	*-1*	*0*	*1*	*2*	*3*	*>*
0-5	*3*	*3*	*3*	*2*	*2*	*1*	*1*	*1*	*1*
6-10	*3*	*3*	*2*	*2*	*2*	*2*	*1*	*1*	*1*
11-15	*3*	*2*	*2*	*2*	*2*	*2*	*2*	*1*	*1*
> 15	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*

Where 1 estimates a stable low-level condition
" 2 " " neutral " " "
" 3 " an unstable low-level condition

Having estimated the stability of the low-level (e.g. surface-300 foot) layer of air it is now possible to represent a best estimate of the diffusion pattern. The visible edge of a diffusing cloud has often been assumed to be approximated by the lateral point at which the concentration falls to 10% of its center line value. The diffusion pattern coordinate system is constructed with its origin at the point of emission, with the X-axis extending horizontally in the direction of the mean low-level wind. The Y-axis is in the horizontal plane perpendicular to the X-axis and the Z-axis extends vertically.

Particles emitted into the air move basically with the air mass. The mean wind speed and direction measured at a fixed point source provides a good estimate of the direction of a plume of particles and their speed of motion. Estimates based on the mean surface wind provide a reasonable diffusion envelope for distances out to about 1/2 of a nautical mile. For greater distances the speed and direction of the plume of particles becomes increasingly dependent upon the vertical profile of wind velocity and to a lesser degree the stability of the low-level air layer.

A stable low-level air layer is considered first. The diffusion pattern from a fixed point source is represented by the following figures.

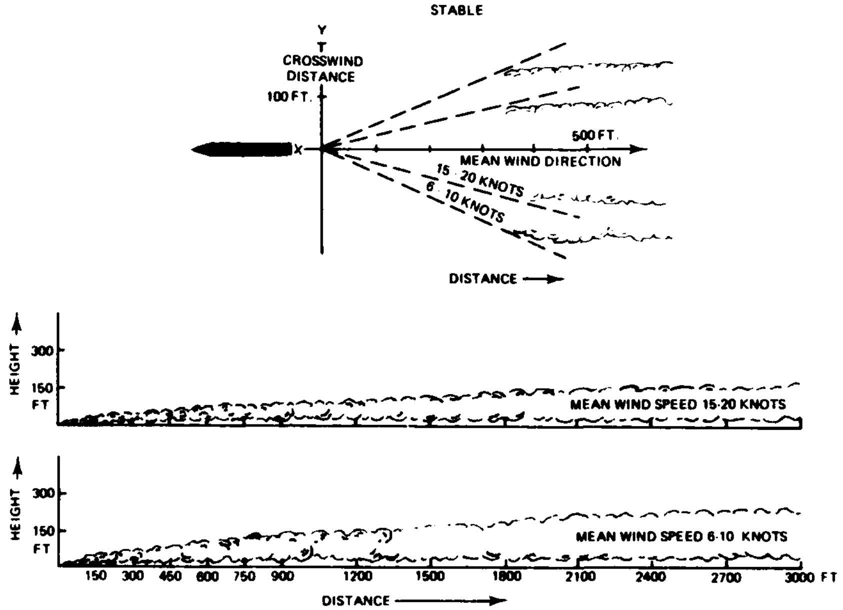

FIGURE 5.1 HORIZONTAL AND VERTICAL DIFFUSION PATTERNS FOR A STABLE LOW-LEVEL CONDITION

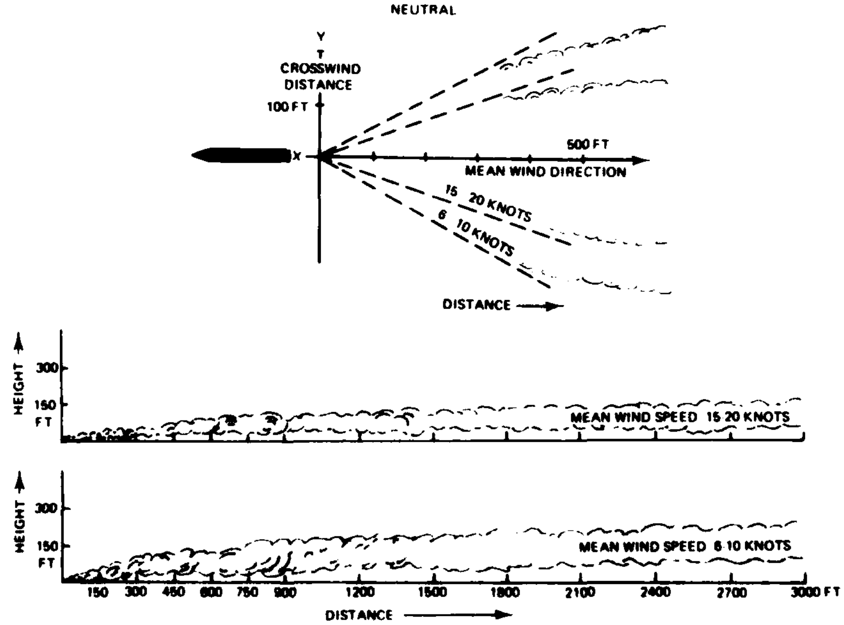

FIGURE 5.2 HORIZONTAL AND VERTICAL DIFFUSION PATTERNS FOR A NEUTRAL LOW-LEVEL CONDITION

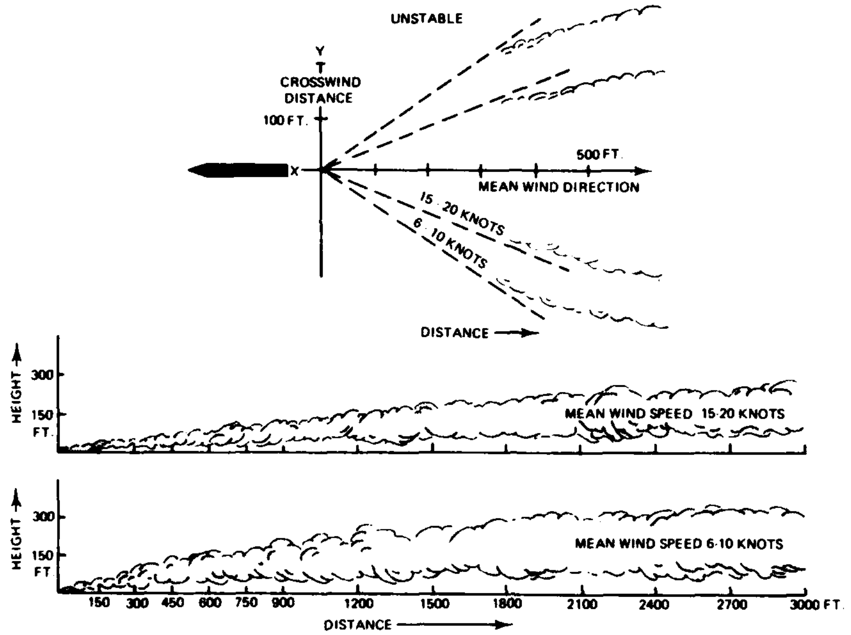

FIGURE 5.3 HORIZONTAL AND VERTICAL DIFFUSION PATTERNS FOR AN UNSTABLE LOW-LEVEL CONDITION

Each of the preceding figures represents an idealized diffusion pattern from a fixed point source. In the case of a ship underway (a moving source) the diffusion pattern is centered on the apparent wind direction. The plume of particles moves in the direction and at the speed of the actual wind, in relation to a fixed point.

The following figures show a ship underway emitting a plume along the apparent-wind vector as the plume moves with the actual wind.

FIG 5.4 APPARENT WIND VECTOR RELATIONSHIP TO THE ACTUAL WIND AND THE SHIPS COURSE AND SPEED

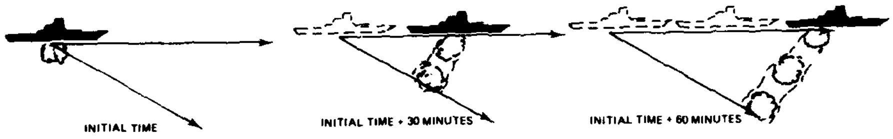

FIG 5.5 TIME SERIES DEPICTING THE DIFFUSION PATTERN FROM A MOVING SOURCE.

The diffusion pattern would exhibit the same characteristics in a stable, neutral or unstable air layer as a fixed point source. The plume would be skewed depending on the angle between the true wind and the ship's course.

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