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METEOROLOGICAL REGIMES FOR THE CLASSIFICATION OF AEROSPACE AIR QUALITY PREDICTIONS FOR NASA-KENNEDY SPACE CENTER

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16. ABSTRACT

This report defines a procedure for developing a statistical air quality assessment for the launch of an aerospace vehicle from the Kennedy Space Center in terms of existing climatological data sets. The procedure can be refined as developing meteorological conditions are identified for use with the NASA-Marshall Space Flight Center Rocket Exhaust Effluent Diffusion (REED) description. Fundamentally, this procedure involves the use of classical climatological regimes for the long-range analysis that can be narrowed as the synoptic and mesoscale structure is identified. Only broad synoptic regimes are identified at this stage of analysis. However, as the statistical data matrix is developed, these synoptic regimes will be refined in terms of the resulting eigenvectors as applicable to aerospace air quality predictions.

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LIST OF DEFINITIONS

Air Quality –	The amount of effluents present in the air. The standards are normally taken for a measurement 2 m above the surface.
Climatological Data Set –	A number of atmospheric soundings used as data inputs to the NASA-Marshall Space Flight Center Rocket Exhaust Effluent Diffusion (REED) description.
Deterministic Air Quality Prediction –	A diffusion prediction using a set of atmospheric parameters (measured or predicted), source term definitions, and a given diffusion model.
Statistical Air Quality Assessment –	The statistical results derived from a number of deterministic air quality predictions.
Surface Transport Layer –	The surface region of the atmosphere which controls the diffusion of the exhaust effluents that influence the surface air quality. The effective depth of this layer can range from a few hundred meters to 4 or 5 km depending on the kinematic and thermodynamic gradients in the atmosphere.

METEOROLOGICAL REGIMES FOR THE CLASSIFICATION OF AEROSPACE AIR QUALITY PREDICTIONS FOR NASA-KENNEDY SPACE CENTER

I. INTRODUCTION

In support of air quality assessments for aerospace vehicle exhaust effluents at Kennedy Space Center, meteorological regimes are defined that can be identified in terms of synoptic conditions. These regimes can be used initially to categorize the air quality statistics that reflect the air quality conditions at launch. As the potential to define more of these prevailing launch conditions improves, the statistical data set can be further narrowed to refine the air quality statistics.

Previously the meteorological inputs to the NASA-Marshall Space Flight Center (MSFC) Multilayer Diffusion Model have been based on climatological data sets for air quality statistics until about 12 hours prior to launch, at which time a deterministic meteorological forecast was made and used as an input. As will be discussed herein, an obvious disadvantage of this approach is that the statistical air quality assessment during the launch preparation period, 2 to 4 days prior to launch, does not reflect atmospheric dynamics for meteorological regimes identifiable from current or predictable synoptic conditions.

Thus, the purpose of defining meteorological regimes in terms of synoptic conditions is to provide a realistic means of classifying subsets of the overall climatological data set for statistical air quality assessments. Since these subsets are more representative of developing atmospheric conditions during the pending launch period than the overall data set, a smoother interface of the statistical with the deterministic air quality assessments is realized. By employing this classification system and the statistical assessment derived therefrom, error bounds for the deterministic predictions can be developed.

Before describing the rationale for development of the meteorological regimes, the meteorological requirements of the NASA-MSFC Rocket Exhaust Effluent Diffusion (REED) description will be discussed.

II. THE NASA-MSFC ROCKET EXHAUST EFFLUENT DIFFUSION INPUT DESCRIPTION

The NASA-MSFC REED description is discussed here only with reference to the meteorological requirements. For a more detailed discussion of the mathematics in the REED description, the reader is referred to the literature [1-3].

The REED description is composed of the NASA-MSFC Cloud Rise Model and the NASA-MSFC Multilayer Diffusion Model. Results from both of these models are strongly dependent on the meteorological inputs. For predictions of surface air quality, normally the atmospheric kinematic and thermodynamic profiles (wind speed, wind direction, virtual temperature, pressure, and density) are obtained either directly or indirectly from a radiosonde sounding or climatological or deterministic prediction for the expected launch. The atmospheric data are selected so as to model each layer as a vertical, statistically homogeneous layer for the area of principal interest. The layer inputs required to support the REED description must have a vertical resolution of not more than 350 m. Boundaries between adjacent homogeneous layers, which are characterized by significant changes in any of the gradients of the kinematic or thermodynamic parameters, must be identified. Hence, the small-scale vertical structure of the atmosphere is required for a diffusion prediction. Although it is desirable to know the variance in the atmospheric kinematic parameters (especially near and at the surface) for the deterministic predictions, these parameters are generally not available; however, reasonable estimates can be obtained from empirical relations derived from available data [4]. Reference 5 gives some typical atmospheric soundings that satisfy the input requirements of the REED description.

III. RATIONALE ON DEVELOPMENT OF REGIMES

To define identifiable, appropriate meteorological regimes for air quality assessments, it is necessary to consider the types of atmospheric data sources available and the applications for which the results of the diffusion predictions will be utilized. The amount of detail required in the atmospheric kinematics is dictated by the planned application of the diffusion prediction. Two extremes in applications are predictions for: (1) air quality and (2) instrumentation deployment. If the Diffusion Model is to be utilized in developing the air quality predictions to ensure public safety, the exactness in the estimates for the atmospheric input parameters such as wind direction can be relaxed in favor of slightly conservative, worst-case values that incorporate a safety factor. Since the desire is to identify any air quality problems, the exact location and concentrations are of secondary importance as long as the error bounds for these estimates have been determined and are reasonably conservative. For this application, routine radiosonde data and meteorological forecasts where homogeneous layers are assumed over the area of interest are satisfactory, since small spatial and temporal changes (less than 10 percent) in the atmospheric kinematic can be neglected without seriously impacting the credibility of the results.

Alternatively, if the application for the diffusion prediction is to support the deployment of a cost-effective (minimum number of instrumented sites) rocket effluent monitoring network or the critical assessment of an identified potential air quality safety problem, the resolution requirements of the atmospheric input parameters for the REED description are very stringent. This increase of rigor is introduced by the need for exactness in the predicted exhaust cloud transit path. In this case, local spatial and temporal changes in the atmospheric kinematics must be considered. This means that terrain effects and the land-sea interface effects must be known. Since the radiosonde sounding provides predominantly vertical information, other sources of data must be used to obtain horizontal-temporal information and to develop the necessary forecast of meteorological parameters over the area of concern. In general, wind tower data are not adequate to totally support this requirement because the available information is limited to the lower part of the planetary boundary layer. Currently, the best source of local spatial-temporal information is a tetroonsonde (a constant level balloon with radiosonde) flown typically at an altitude of 600 m for these purposes. Other potential means to obtain or to improve the local spatial-temporal information would be from simultaneous multiple radiosonde releases or a remote sensing system, provided the system will give adequate coverage of wind and thermodynamic parameters. Hence, exactness in predictions of the exhaust cloud transit path is limited by the available small-scale atmospheric measurement systems and mesoscale forecast schemes.

A diffusion prediction is a common requirement in statistical air quality assessment for planning activities years prior to a launch. Initially, there is a desire to use these statistical assessments in mission planning activities to optimize launch windows. The next planning activity involving diffusion predictions is the support of launch operations beginning 3 or 4 days prior to the launch and continuing until launch time. The meteorological information to support this activity cannot be obtained directly from an atmospheric sounding; it must be obtained from an appropriate atmospheric modeling (forecast) scheme.

A classic means of obtaining the meteorological data for the Diffusion Model is to generate a climatological data set by statistically summarizing the data in the archives into mean profiles [4]. Such climatological profiles are not suitable inputs to the REED description because such a statistical compilation suppresses the small-scale variations and information (less than 1 km)[1] which can, in turn, suppress the extreme downwind ground-level concentrations of primary interest. This is most graphically illustrated in the December 1973 Titan launch radiosonde sounding [6]. In this sounding, a 5°C increase in the surface temperature resulted in a factor of two increase in height for the stabilization of the exhaust cloud using the old cloud rise relations. This difference in stabilization height would result in approximately a factor of eight decrease in the maximum calculated ground-level concentrations of the exhaust effluents. Since the standard deviation about the mean in the surface temperature at Kennedy Space Center during the winter is 3° to 4°C, a significant uncertainty is introduced into the diffusion predictions by the use of a mean temperature profile. (This uncertainty does not exist in this simple form now in the REED description, but it can be introduced by the use ol statistical profiles.) The effects from the other kinematic and thermodynamic parameters are also significant. These statistical effects are overcome by using the actual atmospheric sounding as input to the REED description and then determining the probability distribution of the predicted downwind concentrations to obtain a statistical air quality assessment for use in planning activities.

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[1] The generalizations used here for the length scales are employed to avoid an extremely detailed discussion that would suppress the central issue of the meteorological regimes.

The deterministic kinematic and thermodynamic profiles for prelaunch input to the REED description require a forecast that resolves the small-scale (subsynoptic) structure of the atmosphere. The height and strength of temperature inversions and wind shears are extremely important in defining the depth of the surface transport layer. Stagnant layers in the first 4 km of the atmosphere are primary determinants of downrange effects. Because of the complex coupling of the atmospheric parameters in the REED description, it is difficult to assign a generalized resulting error bound for a given uncertainty for an atmospheric input parameter. However, it must be recognized that an accurate description (measurement and forecast) of the atmospheric layers involved in the downwind cloud track is required for a reliable diffusion prediction.

In general, meteorological regimes that are identified and used to support the REED model program must in some way provide a description of the small-scale resolution of the kinematic and thermodynamic properties. This problem will be addressed in the next section.

IV. METEOROLOGICAL REGIMES TO SUPPORT AIR QUALITY

Before defining the meteorological regimes, the selection and sequential nature of the rationale used in the definition process will be described. Typically, there are approximately nine different synoptic patterns that could be associated with the weather conditions at Kennedy Space Center. Within each pattern, there is a wide variation in the small-scale kinematic and thermodynamic structure depending on the type and intensity of the mesoscale activity (10 to 100 km) present; a representative diffusion prediction is not appropriate to this generalized description. Another disadvantage to working a diffusion classification scheme only on the basis of synoptic weather patterns is that we are more concerned with smooth coherent transition from the synoptic to mesoscale activity. The approach (Fig. 1) is to begin with the statistical air quality assessment that is used in the mission planning activities. As synoptic features begin to define the expected mesoscale activity that will predominate at launch time, the climatological data set is narrowed by utilization of the corresponding meteorological regimes. As the mesoscale activity becomes more clearly developed, further refinements in the selection of the data input for the statistical air quality assessment will be achieved. The final Diffusion Model prediction within a few hours of launch will be based on a forecast of small-scale atmospheric structure and error bounds set by the statistical assessment.

The statistical assessment is based on the following selection process. Initially, the annual-diurnal regimes can be defined; that is, the seasons of the year – winter, spring, summer, or fall – and the time of day – night, morning, afternoon, or evening. These regimes account for the location of the Bermuda anticyclone and heating and cooling effects. In winter the Bermuda anticyclone is located in more southerly latitudes than in summer. The spring and fall regimes are the annual transitional regimes that mark the major movement of the Bermuda anticyclone from southerly latitudes to a more northern

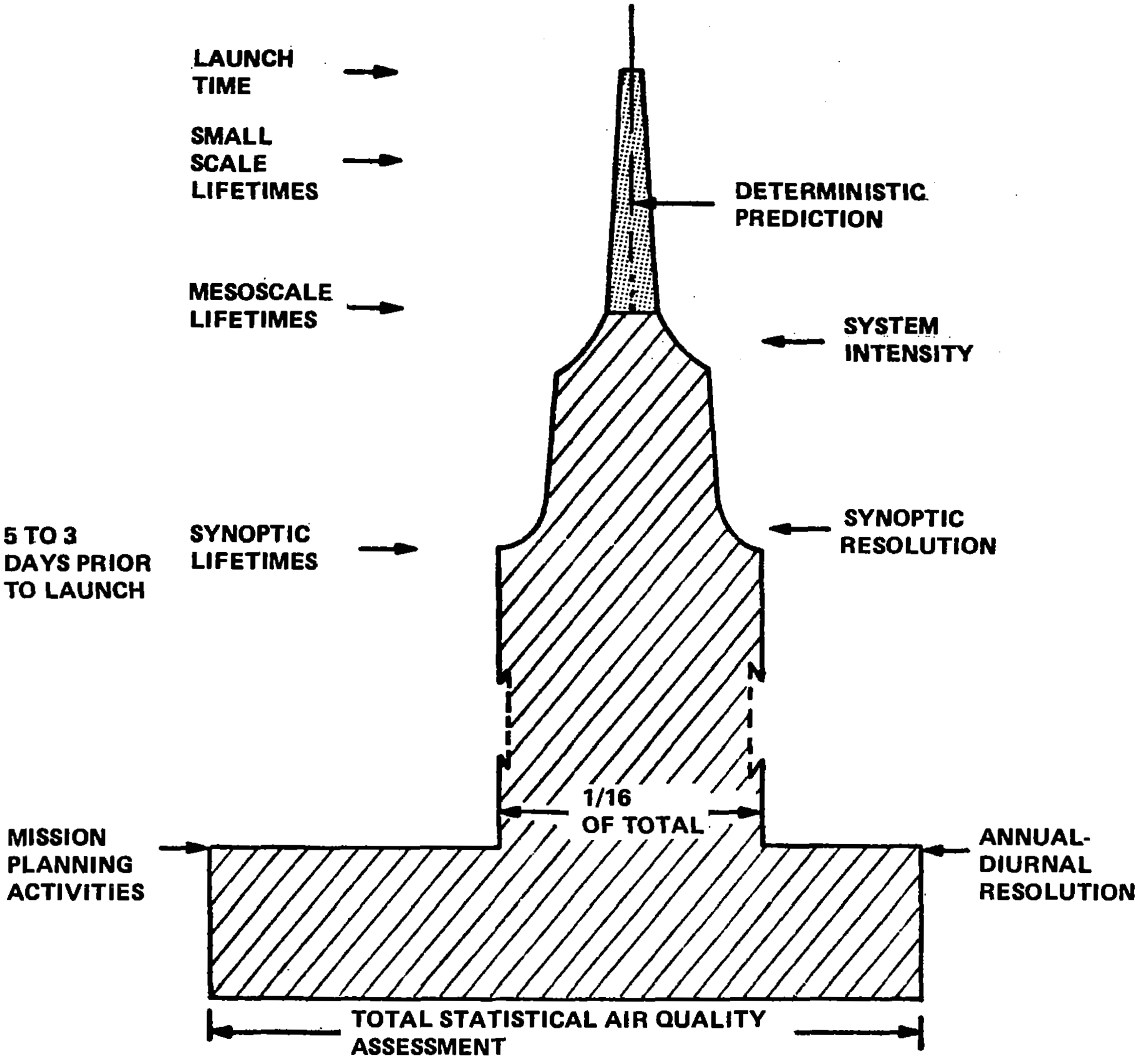

Figure 1. Temporal refinements of assessment.

latitude in spring, or the reverse in fall. The diurnal regime tends to project a small-scale structure to the data set by resolving the solar heating and cooling effects. Here, the morning and evening regimes are the diurnal transitional regimes that are typically marked by the development of any sea-breeze effects or the "burn-off" of any temperature inversion in the morning, and by the development of any land-breeze effects or the development of any temperature inversion in the evening. Two limitations are introduced by these regimes in the statistical air quality assessment: the short duration of the fall and spring transitional season and a lack of temporal resolution in the atmospheric soundings available for analysis. The fall and spring seasons are only approximately 1 to 2 months in duration. During the 1960's at Kennedy Space Center, the highest density of scheduled radiosonde soundings was four times per day; soundings were taken at 0600, 1200, 1800, and 2400 hours during that period. This means that we only have soundings around the beginning and end of each temporal period; hence, the temporal resolution is not adequate for an assessment of the short-term atmospheric dynamics.

The forecast of weather system influence at a specified location is limited to the lifetime of the system, τ, according to

$$\tau = \frac{L}{V} \quad , \tag{1}$$

where L is the scale length associated with the system and V is the velocity of the system. Since synoptic scales are normally a few thousand kilometers and move at from 4 m/s in the summer to 12 m/s in the winter, their lifetime varies from 4 or 5 days to a couple of days in duration. It is impossible to narrow the statistical air quality assessment to less than the annual-diurnal regimes until the launch is within the synoptic lifetime.

As mesoscale lifetimes are approached, the intensity of the system can be classified as strong or weak, thus resulting in a further narrowing of the climatological data set. Within mesoscale lifetimes, the deterministic prediction can be made and supported by error bounds obtained from the statistical assessment. The statistical assessment should be restricted to the climatological data for the governing meteorological regime which potentially bounds the variability of the dominant atmospheric activity.

This approach permits a continuous refinement of the statistical air quality assessment rather than a series of irrevocable steps as the launch time approaches. The flexibility thus achieved permits modification of the prediction scheme as refinements are justified by the results of continuing investigations.

Once the forecast time is within the synoptic lifetime, the meteorological regime that will dominate the mesoscale structure at launch time can be identified. The principal meteorological regimes that can be identified in the beginning of the synoptic lifetime are:

- The Bermuda anticyclone and associated easterly winds.
- Easterly waves and associated strong vertical mixing prior to passage of the wave trough.

- Westerly waves and associated frontal activity.
- Continental anticyclone.

These synoptic regimes can be utilized to further narrow the statistical air quality assessment and render it more relevant to the developing conditions (Fig. 2). For example, as we approach the mesoscale lifetime, the strength of the regime can be forecasted. The statistical air quality data will be so organized that when the location of a system can be forecasted for launch time, the statistical assessment will reflect this information.

Thus, by the initial selection of the annual-diurnal regime, the selection of the synoptic regimes at synoptic lifetimes, and the selection of intensity of the regime at near-mesoscale lifetime, a flexible procedure has been defined to optimize the available atmospheric information for the support of launch air quality analysis as launch time approaches. At the same time, the statistical data will be so structured as to permit even more detailed assessments when atmospheric conditions warrant. The matrix of synoptic regimes for the annual-diurnal regimes can be resolved, based on the data set analysis, into its eigenvectors in accordance with the development of the analysis. Premature definition of exact synoptic regimes could result in an insufficient data set for adequate statistical definition. Hence, there is a desire to maintain flexibility in the definition of regimes until they are fully supported by data analysis.

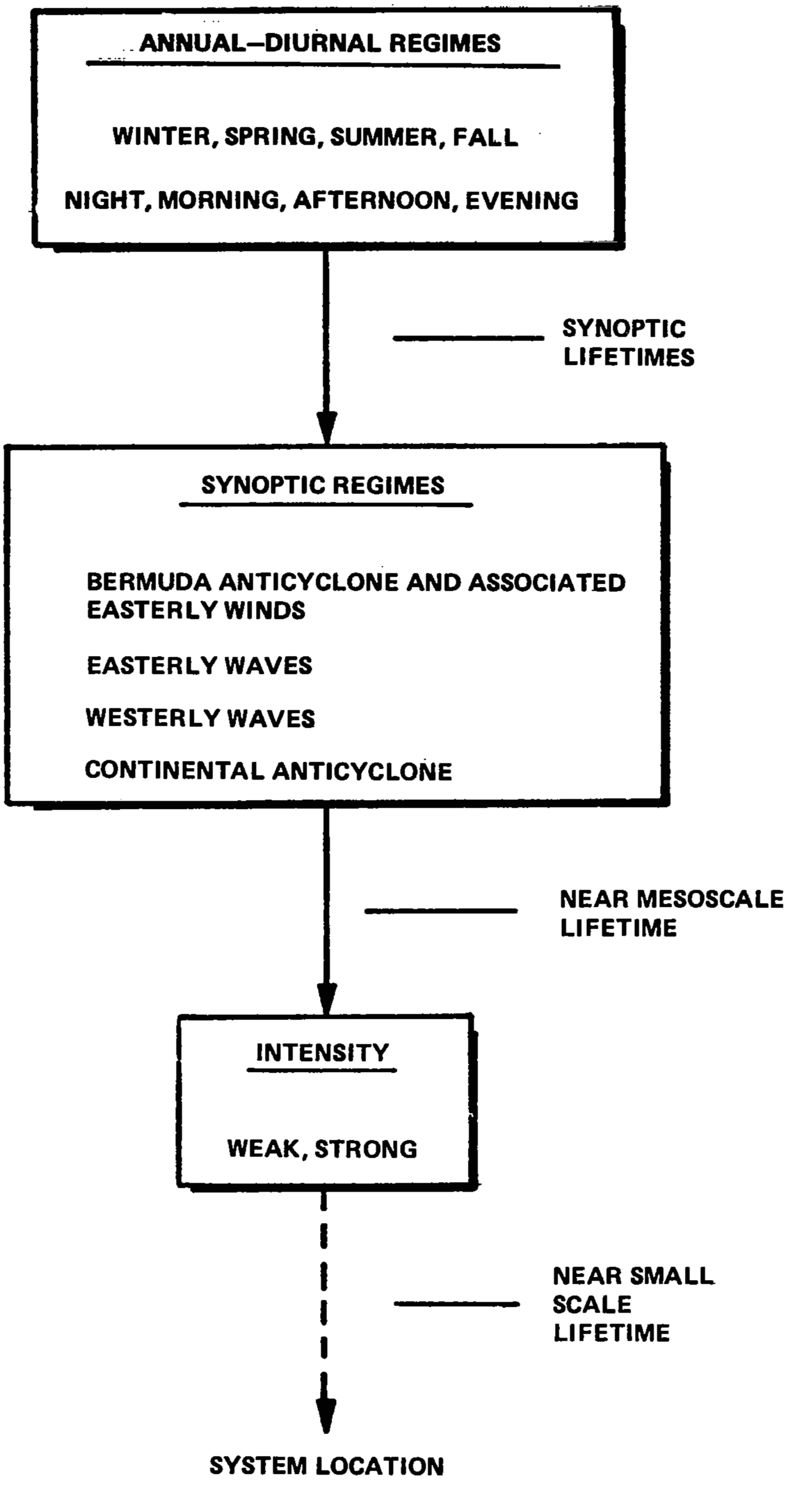

Figure 2. Flow chart of meteorological regimes.

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