In a related question, Dr. Tucker asked whether the NMC models were capable of describing adequately the growth and movement of hurricanes. Dr. Shuman replied that hurricanes, because of their unique meteorological structure, could only be adequately handled by special models. At present, hurricanes were treated as a point advected in a barotropic model. During hurricane situations, this advection procedure is performed every 12 hours and the results forwarded to NMC.

In commenting on the time required to manually remove an established bias from the products of a particular numerical system, Dr. Gibbs asked whether the forecasting process might be facilitated by the incorporation of automatic correction techniques in the numerical system. Dr. Shuman supported this suggestion but pointed out that with the continual updating of numerical models at operational centers it was very difficult to establish an appropriate climatology on which the automatic correction technique could be based.

Mr. Kelly suggested that an additional factor associated with the considerable improvement in forecasting skill at NMC since the advent of numerical prediction might be the availability of satellite information over sparse data areas. Dr. Shuman replied that although the improvements in the observation system (aireps, satellite photos, etc.) undoubtedly contribute to the skill achieved, the principal source of Numerical Weather Prediction improvement must be due to model development. Dr. Shuman based this judgement on the sharp favourable reaction observed in skill scores, following the introduction of new models into the operational system.

Mr. Rutherford enquired as to the present extended range forecasting potential of models similar to that used operationally by NMC. Dr. Shuman replied that although there was currently considerable theoretical speculation as to the ultimate limit of predictability, the practical limit of present models in the Northern Hemisphere was around five days.

D. G.

10 July 1970

THE INVERSION PROBLEM IN INDIRECT SENSING OF THE ATMOSPHERE

by S. Twomey

In his opening remarks, Dr. Twomey of the C. S. I. R. O. Division of Radiophysics, Sydney, mentioned some of the problems, especially in the field of atmospheric physics, that involved the solution of an integral equation. This equation arises when indirect sensing methods are used to determine the profile of a parameter distributed throughout the atmosphere. Examples given included:

the use of ultra violet measurements to determine the vertical distribution of ozone, infra-red measurements of temperature, microwave to ultra violet measurements of aerosols and clouds, and in the design of specialised filters. In each case computation of the vertical distribution of the required parameter involved the solution of integral equations of the form:

$$F(y) = \int f(x, y)\, k(x)\, dx$$

One does not expect to compute the unknown parameters (e.g. temperature profile) exactly using a few not too accurate measurements (in this case, of infra-red radiation). Sources of error include approximations made in the lineariz-ation of the Planck function and the use of a single transmittance function and, generally, if we made "n" observations it doesn't follow that we get "n" *independent* observations. In the case of infra-red measurements it is not a question of the importance of the number of channels in which radiation is being measured but rather the importance of the independence of the measurements.

It is possible to produce synthetic temperature profiles with which are associated specific radiances, but when the radiances are used in an inversion scheme to get temperature profiles, numerical instability can lead to meaningless results.

The speaker mentioned relationships between the properties of matrices and the numerical solution of the integral equations. Associated with a matrix is a set of eigenvectors which are mutually orthogonal. One of the steps in the solution involves division by each of the eigen values. As a typical eigen value may be about 10^{-6}, this results in errors in the measurements being increased by 10^{6}, in which case the "signal" may be completely swamped by this error-magnifying mechanism in the algebra. In the limiting case of a singular matrix, the magnification of the error would be infinite. The problem is that the radiation measurements are made close together in terms of wavelength and are therefore fairly highly correlated. In relation to ozone, Herman and Yarger computed the eigen values for wavelengths in the ultra-violet. The first three eigen values ranged from approximately 10^{-2} to 10^{-3} and the last 10^{-11}, indicating that about four measurements only were independent; that is, others could be predicted from these four. In one experiment involving fifty measurements, only seven were independent. Usually between four (pessimistic) and eight (optimistic) are taken to be independent.

Some results were presented indicating that in a set of twenty-two (22) measurements made with an accuracy of $\frac{1}{2}$ to 2%, only about 3 independent inferences could be drawn. With an accuracy of 2 to 5%, the number of independent inferences was 2 to 3.

It appeared to be fundamental that an indirect sensing system involving a smooth kernel gives only 4 to 8 independent inferences.

An error analysis indicated that the number of independent inferences was roughly linear (actually slightly curvilinear) with the number of decades change in the absorption parameter. Also a change by a factor of 1000 in the mean square error was equivalent to a change of about 2 decades (100) in the absorption parameter. However, in a given physical situation it is not generally possible to use a variation of many decades in the absorption parameter. For example, the variation in the absorption parameter for ozone is less than one decade.

Summarising, the speaker said that generally, given a set of data, an infinite number of solutions will satisfy the data. It is necessary to use an externally-based process of selection to choose the correct solution, e.g. a selection process based on *a priori* knowledge of the atmosphere.

It appears that the number of independent bits of information are related to the range of the input data, that is, the ratio of largest to smallest.

In answer to a query by Mr. McRae (Bureau of Meteorology), the speaker suggested that it might be preferable for any country receiving SIRS data to carry out the reduction locally rather than depend on the reduction of the launching country. In this way extra information might be obtained. A large number of radiosonde and aircraft upper air data could be used as a catalogue from which optimal empirical orthogonal functions could be derived which could be then used to optimize the SIRS temperature accuracy.

In reply to another question, the speaker said that the inversion process depended on an initial arbitrary estimate of the permissible error, then the procedure was standard and would produce a fixed answer that is objective, not subjective.

In a discussion with Mr. Clarke (C. S. I. R. O., Aspendale) it was stated that a point tropopause could not appear because such a tropopause represented a very high frequency which is well outside the capability of the present system.

F. C.

19 August 1970

CLEAR AIR TURBULENCE

by K. T. Spillane

Dr. Spillane, Superintending Meteorologist of the Research and Development Division, Bureau of Meteorology, discussed his analysis of Jindivik flight records. This study was initiated at the Meteorology Department, Melbourne University, by Radok and Rider and continued by Spillane as Senior Research Fellow with the support of a Department of Supply grant to the Meteorology Department. The Jindivik target aircraft at the time were the only aircraft aside from U2's regularly exploring the