The ANMRC tropical analysis scheme

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A univariate optimum interpolation analysis scheme has been developed for operational and research use over tropical latitudes. Features of the scheme include its three dimensional aspect, the choice of sigma (normalised pressure) as the vertical coordinate and the use of frictionally-corrected surface wind observations to delineate near-equatorial systems and the Australian summer heat low.

The analysis procedure is illustrated using a situation that occurred during the Winter Monsoon Experiment (WMONEX). Assessment by operational forecasters, and by comparison with available subjective analyses, indicates that the numerical product is comparable in skill to manual analyses and suitable for operational use. Moreover, given an observing network comparable to that of WMONEX, meaningful synoptic-scale divergence fields can be obtained from the analysed winds, suggesting that the analysis method is assimilating the observations in a physically realistic manner.

Introduction

The Bureau of Meteorology in Australia has an operational requirement to provide large-scale analyses and prognoses for the Australian tropics and adjacent areas. The Australian Numerical Meteorology Research Centre (ANMRC) has recently begun a research project to investigate the feasibility of performing some of these functions by objective numerical techniques. The long-term aim is numerical weather prediction in the tropics but at present there is little understanding — or even documentation — of the nature of the large-scale flow changes that take place in our region. Therefore a need also exists for diagnostic research into the tropical weather phenomena that affect the Australian region.

To help satisfy these operational and research needs, a three-dimensional univariate optimum interpolation scheme has been constructed which we think will satisfy the dual roles, and which possesses a number of features to handle the currently available observing network and synoptic situations peculiar to the Australian tropics and near-equatorial regions.

The scheme’s capability for operational analysis purposes is illustrated by comparison with operational analyses from the Darwin Regional Meteorological Centre and from the WMONEX Centre. Its information content for diagnostic research is demonstrated by comparison of analysis divergence fields with observed cloudy and clear areas.

Analysis strategy

It is well known that in tropical latitudes, since the coriolis force is small and since synoptic scale temperature variations are of the same order as the errors in the observations, diagnosis of the windfield from the mass field would lead to erroneous analyses, thus making it necessary to base a tropical analysis scheme primarily on winds.

The analysis method that seems the most appropriate in terms of available computing resources, overall flexibility, and allowance for observations of mixed quality is optimum interpolation. First developed by Gandin (1963), the technique involves correcting a first guess at any location, using the observations in the vicinity of the location and ideally, the history of the temporal and spatial correlations between the observations. In our case the first guess is provided by either climatology or a previous analysis (persistence).

Working versions of optimum analysis schemes have been developed by Rutherford (1973, 1976), Schlatter (1975), Schlatter et al. (1976), Jones (1976) and Bergman (1979), while tropical wind analysis schemes have been developed by Bedient and Vederman (1964), Bedient et al. (1967), Dartt (1972) and Jones (1976). The main advantages of the optimum analysis technique are detailed by the former authors. For our purposes the most important features are that it can handle observing systems and first guess fields of mixed
quality in a sensible way.

The particular problems posed by employment of the system in the Australian tropics, coupled with the often conflicting requirements of future operational and research use, has meant that particular features from the schemes referred to above have been incorporated in the present system. The most important of these are:

(i) the three-dimensional aspect of the scheme to improve vertical consistency and eliminate the problem of assigning levels to 'off (standard) level' observations;

(ii) the use of surface synoptic data — after allowance for frictional effects (Gray 1972) — to fully delineate the Australian summer heat low, and to incorporate ship and island wind observations, particularly from the equatorial Pacific and Indian oceans;

(iii) the choice of sigma (pressure divided by surface pressure) as the vertical coordinate — this foreshadows the development of an analysis-forecast system and avoids continual interpolation between analysis pressure levels and forecast model sigma levels over no data areas;

(iv) a manual interaction facility by insertion of bogus data to enable forecasters to locate systems in a manner consistent with the satellite picture and with advice from other international meteorological centres.

We have chosen a univariate interpolation scheme in which the meteorological variables, mean sea level pressure, zonal wind (U), meridional wind (V), temperature (T), and moisture are analysed independently. This choice has been made mainly influenced by available computing resources, with secondary considerations being analysis accuracy and the varying requirements of operations and research. However, since independent wind component analysis does not seem to unduly diminish overall analysis accuracy (Kostyukov and Kochergina 1979) and since the wind and mass fields will later be combined using a variational adjustment technique (Sasaki 1958, 1970; Jones 1970; Seaman et al. 1977) to allow the analysis of one variable to help that of another, the choice of a univariate, rather than a multivariate, scheme, is not expected to affect the quality of the tropical wind analyses.

In summary, the analysis strategy we have chosen to pursue is three-dimensional univariate optimum interpolation on a latitude-longitude grid on sigma surfaces, followed by a variational adjustment step. This report gives details of the interpolation stage.

**Optimum interpolation**

**Formulation of equations**

Detailed derivation of the optimum interpolation equations are given in the standard references, Gandin (1963, 1964), Alaka and Elvander (1972), Rutherford (1973, 1976), Schlatter (1975) and Bergman (1979). The equations result from a straightforward minimisation of the mean-square interpolation error. That is, if the optimum estimate of $f'$ at point 0 is given by

$$ f'_0 = \sum_{i=1}^{N} p_i \hat{f}_i + l_0 $$

where primes indicate normalised deviations from an initial guess divided by the error variance of the guess, $p_i$ are optimum weights to be determined, $n$ is the number of observations, the circumflex indicates the observed values, and $l_0$ is the interpolation error, then the weights can be determined from the condition that they minimise the mean-square interpolation error. That is, they are obtained from the $n$ equations

$$ \sum_{j=1}^{n} (\mu_{ij} + \lambda_{ij} \rho_{ij}) p_j = \mu_{oi} \quad i = 1, \ldots, n $$

where $\mu_{ij}$ is the spatial correlation of guess field error between observing locations $i$ and $j$, $\rho_{ij}$ the corresponding spatial correlation of observational errors, $\mu_{oi}$ is the spatial correlation between interpolation point 0 and observing location $i$, and $\lambda_{ij}^2$ is the ratio of the observational and guess field error variances given by

$$ \lambda^2 = \sigma^2 / \sigma^2 $$

where $\sigma^2$ and $\sigma^2$ denote the respective variances.

Analysis reliability is determined from the normalised minimum mean square error

$$ \epsilon_{MIN} = \frac{E^2}{\sigma^2} = 1 - \sum_{i=1}^{n} \mu_{oi} p_i $$

where $E^2$ is the mean square analysis error.

The normally satisfactory assumption used in the derivation of the above equations is that the observational errors are uncorrelated with the true values of the measured quantities.

**Correlation functions**

For simplicity we assume that the three-dimensional guess field error correlations can be expressed as the product of a horizontal function (at constant pressure) and a vertical function. That is, the correlation between location $i$ (with coordinates $x_i$, $y_i$, $p_i$) and location $j$, takes the form

$$ \mu_{ij} (x_i, x_j, y_i, y_j, p_i, p_j) = \Psi_{ij} (x_i, x_j, y_i, y_j) \cdot \alpha_{ij} (p_i, p_j) $$

where $\Psi_{ij}$ is the horizontal function and $\alpha_{ij}$ the vertical function.

Experiments conducted with different horizontal wind component correlation functions suggested by Rutherford (1972) and Bergman (1979) indicate only low analysis sensitivity (maximum analysis differences at jet stream level of up to 5
knots over data areas) to the analytic form of the function and moderate sensitivity (maximum differences up to 15 knots) to the width of the function, particularly when extrapolating into no data areas. We have chosen Bergman's formulation because these functions fit the correlations from real data in the Australian region more closely, and because anisotropic functions seem to preserve jet stream structure a little better. They take the form

\[ \psi_{ij}^{uu} = -\frac{1}{2} \exp\left(-k_h s^2\right) \left[ -\frac{1}{2} \left(\lambda_i - \lambda_j\right)^2 \cos (\Phi_i + \Phi_j) - 2 \right. \\
\left. - k_h R^2 \left(\lambda_i - \lambda_j\right)^2 \cos \frac{1}{2} (\Phi_i + \Phi_j) \sin \frac{1}{2} (\Phi_i + \Phi_j) + 2 (\Phi_i - \Phi_j) \right] \cos \Phi_i \cos \Phi_j \]

where \( k_h = 0.6 \times 10^{-6} \text{km}^{-2} \), \( R \) is the radius of the earth, \( \lambda \) is longitude, \( \Phi \) is latitude, and \( s \) is the distance between locations \( i \) and \( j \) on the earth's surface. The function \( \psi_{ij}^{uu} \), as well as observed summertime wind component correlations at the 500 mb level over the Australian region, is shown in Fig. 1. The correlations are based on deviations from climatology, and as such are appropriate for the first guess field used in the following discussion. For more skilful guess fields the value of \( k_h \) is larger. The function \( \psi_{ij}^{vv} \) is similar to \( \psi_{ij}^{uu} \), but with the axes swapped. Because of random errors, the observed correlations at zero separation will not in general be unity and thus the analytic correlation functions have been scaled to offset this problem. The rather small value of \( k_h \) will result in relatively smooth analyses, with each observation having a large area of influence. However this parameter, and indeed all the correlation functions, can clearly be changed as more statistics and better guess fields become available.

The vertical correlation function for component winds, depicted in Fig. 2, is also obtained from Bergman's NMC scheme and is given by

\[ \alpha_{ij}^{uu} = \alpha_{ij}^{vv} = \frac{1}{1 + k_p \left(\ln \left(p_i/p_j\right)\right)^2} \]

where \( k_p = 5 \). It should be noted that the function decreases rapidly with increased vertical pressure separation, particularly at high levels, and thus observations only exert an influence in the vertical over about a 3000 metre layer.

Since rawinsonde observations have correlated errors (Hollett 1975) their information content is reduced (Bergman and Bonner 1976; Seaman 1977(b)). This spatial correlation of observational errors (\( \rho_{ij} \) in Eqn 2) is modelled using Eqn 8 with \( k_p = 7 \).

Fig. 1 Horizontal correlation function for zonal wind component computed from Eqn 6 with \( k_h = 0.6 \times 10^{-6} \text{km}^{-2} \). Observed summer time correlations at 500 mb over the Australian tropics are shown for comparison. Correlations are of variable point \( i \) with point \( j \) located at the origin. Tick marks along margins are at 150 km intervals. The vertical axis is distance north (or south) and the horizontal axis is distance east (or west).

![Fig. 1](image1.png)

Fig. 2 Vertical correlation function for component winds computed from Eqn 8 with \( k_p = 5 \).

![Fig. 2](image2.png)

**Observational data and error variances**

The analysis scheme has been tested on situations during the Winter Monex period. The data source is a blend of the Winter Monex Quick Look set, the routine southern hemisphere network, GMS
and Indian Ocean satellite winds derived by the University of Wisconsin, and some FGGE drop-windsondes.

The observational and guess field errors enter the optimum interpolation equations through the parameter $\lambda$ of Eqn 2. For the observations, the following random errors apply:

- Rawindsonde: 3 knots
- Airep/Codars: 4 knots
- Surface wind from ships corrected for friction: 4 knots
- Satellite: 6 knots
- Surface wind from land stations greater than 7 knots and corrected for friction: 7 knots

The incorporation of surface wind observations from land stations was found to be necessary to fully delineate the northern Australian summer heat low. The heat low is a shallow but important feature of the summer circulation over the Australian tropics and can often only be defined by the surface observing network. Wind observations from island stations are also being used on the advice of operational forecasters who have emphasised their importance as a data source over the South Pacific region. The minimum speed criterion of 7 knots is a crude attempt to remove the influences of diurnal variation and local wind effects.

The standard deviation of the wind component guess field has been derived from Australian region climatological data (Maher and McRae 1964). To retain the latitude and height variability it is modelled by the simple relation

$$\sigma_g = 35 - 20 \exp\left(-\frac{|\text{latitude}|}{\sigma_p/10}\right)$$

where $\sigma$ is the vertical coordinate, $\rho/\rho_0$.

Our lack of experience with the analysis scheme has meant that many a priori decisions have had to be made about the observation and guess field error variances. Work is currently underway to improve the specification of the statistics by generating improved climatological fields and correlation functions over the Australian tropical region using output from the analysis package and the raw observations.

**Data quality control**

Observation checking occurs in two phases. The first is a gross error check which eliminates data with incorrect date or time, checks for message inconsistencies like dew-point temperature exceeding dry bulb temperature, validates sonde flights with hydrostatic and wind shear checks, and rejects observations which exceed pre-set climatological bounds. The second phase is a finer error check and can be done either using the optimum interpolation scheme, or by comparing each observation with its neighbours. The first technique, although more reliable, was computationally expensive and thus the second method of buddy checking was implemented. This involves comparing all possible pairs of observations used for the analysis at a particular grid point using the criterion

$$|\text{obs}_i - \text{obs}_j| \geq k(a - b \mu_{ij}) \sigma_g$$

to flag possible incorrect data. $a$ and $b$ are empirical constants, equal to 4.5 and 2 respectively for winds, and $k$ is a measure of the relative reliability of observations $i$ and $j$. If an observation is flagged by three or more of its neighbours, it is rejected. The criterion allows tolerances to be varied with latitude and height and to be tightened over data dense areas and eased over data sparse areas. Although this observation checking scheme was generally effective, manual monitoring of data was still found to be necessary. If the observations being checked are poorly correlated, or if a number of self consistent but incorrect observations (satellite cloud winds in particular) are present, then incorrect data can escape the rejection criterion.

**Data search and selection**

The analysis is computed along parallel lines from south to north. Estimates of each variable at all grid points in a vertical stack are obtained before moving to the next vertical stack in a line. For each vertical stack all observations within a cylindrical volume around the stack are collected — the size of the cylinder depending on the data density. The maximum radius the cylinder can have is 1200 km. From each quadrant surrounding a grid point, the two observations with the largest weights — determined by

$$W = \frac{\mu_{ij}}{(1 + \lambda_i)}$$

are selected to perform the interpolation to each grid point in the stack. If quadrants are void of observations, more observations from the other quadrants are selected. If all quadrants are void, the guess value at the grid point is retained. The selection procedure is designed to try to choose, as efficiently and accurately as possible, those observations that would receive the largest weights in the interpolation if all observations

**Analysis procedures**

**Pre-analysis**

After undergoing gross error checks, observations are sorted into $10^6 \times 10^6$ latitude-longitude boxes. A mean sea level pressure analysis using optimum interpolation is performed first, from which the surface pressure analysis is obtained. A pre-analysis program then calculates normalised observation minus guess field values and assigns observation errors and the correct sigma level using the observation pressure and the surface pressure analysis.
were used. It allows good quality observations to be selected even though they may be somewhat further away from the grid point than others which are less reliable.

Figure 3 illustrates observed and analysed winds at the 0.95 sigma level over the South China Sea—Indonesia region and shows the observations that have been selected to perform the zonal wind component interpolation at the grid point indicated.

An example of the tropical analysis

Although analysis skill is difficult to assess, it was felt that the best available methods for testing the numerical analyses were: by examining the fit of the analysed fields to the data; through subjective assessment by operational forecasters and comparison with available subjective analyses; and finally by testing the scheme’s ability to indicate large-scale cloudy and clear areas from divergence fields derived from the analysed winds. This and following sections are devoted to pointing out the virtues and deficiencies of the numerical scheme for operational and diagnostic research use. To maintain maximum objectivity during assessment, no attempt has been made to force the analysis with bogus observations. The first guess field is climatology. The horizontal resolution is 2.5° on the latitude-longitude grid.

Synoptic situation

Figures 4 to 7 illustrate the tropical wind analyses at the 950 and 200 mb levels, the mean sea level pressure analysis and the infrared satellite cloud picture for 0000 GMT 2 December 1978. (For operational and display purposes, a post processor step interpolates from sigma to pressure surfaces using cubic splines.)

The main synoptic features evident on the charts and satellite cloud picture are: major subsidence regions associated with high pressure systems located over the Indian Ocean near 30°S, 100°E, over the Tasman Sea near 40°S, 160°E, over the north Pacific near 35°N, 155°E and over mainland China; frontal systems crossing Japan and south central Australia; a tropical cloud cluster near the Philippines; the south Pacific cloud band near Fiji; and equatorial trough, intertropical convergence zone activity near Indonesia, New Guinea and further to the east.

Fig. 3 Low-level observations and interpolated vector winds at the 0.95 sigma level for 0000 GMT 2 December 1978. Radiosondes are designated with a ‘.’, satellite cloud winds with ‘o’, and surface synoptic winds with ‘+’. The observations circled are those that have been used to perform the zonal wind component interpolation to the grid point •. 
Fig. 4 950 mb objective streamline and isotach analysis for 0000 GMT 2 December 1978. Winds are measured in knots.

Fig. 5 200 mb objective streamline and isotach analysis (knots) for 0000 GMT 2 December 1978.
Fig. 6 Objective mean sea level pressure analysis (mb) for 0000 GMT 2 December 1978.

Fig. 7 GMS cloud picture for 0000 GMT 2 December 1978.

GMS1 1P 2333 78 DEC 02 00Z
Table 1. Observation minus analysis statistics in knots for rawinsonde and satellite observations.

<table>
<thead>
<tr>
<th>Observing Platform</th>
<th>Level (mb)</th>
<th>Number of obs</th>
<th>Wind vector errors</th>
<th>Mean absolute u, v component error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bias</td>
<td>r.m.s. error</td>
</tr>
<tr>
<td>Rawind</td>
<td>950</td>
<td>112</td>
<td>1.2</td>
<td>6.7</td>
</tr>
<tr>
<td>Satellite</td>
<td>950</td>
<td>482</td>
<td>0.9</td>
<td>5.9</td>
</tr>
<tr>
<td>Rawind</td>
<td>200</td>
<td>149</td>
<td>2.9</td>
<td>8.9</td>
</tr>
<tr>
<td>Satellite</td>
<td>200</td>
<td>96</td>
<td>-1.1</td>
<td>13.7</td>
</tr>
</tbody>
</table>

**Fit of the analysed fields to the data**

Table 1 illustrates the wind speed biases, root mean square errors and standard deviations of observation minus analysis values for the two main observing platforms (rawinsonde and satellite) at the 950 and 200 mb levels. To obtain these statistics, observations within 40 mb of 950 mb and within 25 mb of 200 mb and differing by less than 60 knots from the analysed value have been compared with horizontally interpolated analysis values. No vertical interpolation has been performed.

The main conclusions to be drawn from the statistics are: (1) there is a slight bias towards underestimating wind strengths (this may be caused by the poor first guess field), and (2) at the lower level the relative magnitudes of the r.m.s. errors suggest that the observational errors and the data selection method need finer tuning, so that satellite winds do not overwhelm rawinds.

The fit of the analysis to the data can also be seen qualitatively from Fig. 3. It should be emphasised that because the first guess field is so poor and the correlation functions so broad, many smaller-scale features have been smoothed. For example because of the influence of the surrounding observations, the ship wind very close to the grid point indicated is not well paid. This sort of occurrence can only be overcome by the use of improved guess fields or more general availability of better data bases to improve the specification of the correlation functions at smaller scales.

**Subjective assessment for operational use**

Subjective assessment by experienced analysts from the Darwin Regional Meteorological Centre of this, plus a number of other analyses, suggests that the numerical product is skilful and reliable in reproducing the large-scale flow. The strength and location of synoptic-scale systems are generally well analysed and consistent with the observations and the cloud picture. Lack of skill over no data areas can generally be traced to the poor first guess of climatology and considerable improvement in analysis quality results from the use of persistence as first guess.

Further evidence supporting the quality of the numerical analyses can be gained by comparison of these charts with available subjective analyses from the Darwin Regional Meteorological Centre and the operational Winter Monex Centre (Figs 8 to 11). Examination of these analyses indicates considerable similarity between the numerical and Darwin charts. The location of virtually all systems, and in particular that of the near-equatorial trough and the tropical depression over the South Pacific, are identical: while at the upper level, the location of the subtropical ridges and major outflow centres are also consistent. However, some differences are evident on the operational WMONEX chart. For example in the low-level flow near the Philippines and near Java, and in the upper-level flow over New Guinea. These differences, and in fact the differences between the three analyses, can be mostly attributed to the different data bases, to the slightly different weighting given to low-level satellite winds and surface winds, and to the different methods of interpreting the wind field from the cloud picture. It should be noted at this stage that the quality of the objective analyses is only slightly diminished by withholding satellite cloud wind observations. That is, the improved data base for the numerical product may be producing the increase in analysis skill necessary to match that of the manual product. Figure 12 is the 200 mb numerical analysis produced without satellite wind observations — that is from a data set that is considerably smaller than even the operational data set. There are clearly some differences over the major ocean areas, particularly the Pacific, but in general it still compares favourably with the manual analysis. At the lower levels the differences are even smaller, with ship and island-station observations seemingly providing sufficient information to analyse the low-level flow.

**Divergence fields from analysed winds**

For ease of interpretation and comparison with previous works, we have calculated divergences on pressure surfaces. Interpolation errors from sigma to pressure surfaces have been minimised by analysing on sigma levels 0.95, 0.85, 0.70, 0.50, 0.30, 0.20 and 0.10 which correspond closely — except at low levels over mountainous terrain — with pressure levels at 950, 850, 700, 500, 300, 200 and 100 mb. Maximum differences between
Fig. 8 Operational 900 mb streamline and isotach analysis (knots) for 0000 GMT 2 December 1978 from Darwin RMC.

Fig. 9 Operational 200 mb streamline and isotach analysis (knots) for 0000 GMT 2 December 1978 from Darwin RMC.
Fig. 10 Operational low-level streamline and isotach analysis (knots) for 0000 GMT 2 December 1978 from WMONEX Centre.

Fig. 11 Operational 200 mb streamline and isotach analysis (knots) for 0000 GMT 2 December 1978 from WMONEX Centre.
the pressure surface and corresponding sigma surface wind components are approximatley three knots and thus the interpolation error over level terrain will not affect the divergence calculation.

In pressure coordinates on a latitude-longitude grid the diagnostic vertical motion equation is given by

$$\frac{\partial \omega_p}{\partial t} = - \int \nabla_p \cdot \nabla_p \, dp$$

$$= - \int \left[ \frac{1}{R \cos \Phi} \left( \frac{\delta u}{\delta \lambda} + \frac{\delta v \cos \Phi}{\delta \phi} \right) \right] \, dp$$

where $R$ is the radius of the earth, $\Phi$ and $\lambda$ are latitude and longitude, and $u$ and $v$ are zonal and meridional wind components. Because of wind measurement and analysis errors, formation of the divergence term $\nabla_p \cdot \nabla_p$, from the analysed winds, is prone to errors. However because of the obvious close relationship between divergence and weather it is worthwhile seeing if the increased observing network during WMONEX, together with the univariate optimum analysis method, can produce physically realistic large-scale divergence fields from the analysed winds.

Divergence fields have been obtained from the interpolated winds and then passed once through a five point filter to remove some of the small-scale roughness caused by the analysis method or by slightly incorrect data. Application of the filter results in less than a 10 per cent reduction in amplitude of the large-scale, active divergent and convergent regions. Figures 13 and 14 depict the divergence fields in units of s\(^{-1}\) at the 950 and 200 mb levels. The singly hatched regions are areas where the divergence exceeds $5 \times 10^{-6}$ s\(^{-1}\). The doubled hatched regions are similarly defined convergent regions.

Examination of the satellite cloud picture (Fig. 7) in conjunction with the divergence fields indicates considerable compatibility between the active, large scale cloudy and clear areas and the low level convergent and divergent regions. In particular, the main areas of activity over south central Australia, Indonesia, near the Philippines, the south Pacific and over Japan are all characterised by vertically-consistent low-level convergence and upper-level divergence, with the reverse mechanism operating in the subsident regions over the Indian Ocean, the Tasman Sea, the north Pacific and mainland China. Admittedly
Fig. 13 950 mb divergence field in units of $10^{-6}$ s$^{-1}$. The contour interval is $5 \times 10^{-6}$ s$^{-1}$. Hatched areas are greater than $5 \times 10^{-6}$ s$^{-1}$. Doubly hatched areas are less than $-5 \times 10^{-6}$ s$^{-1}$.

Fig. 14 200 mb divergence in units of $10^{-6}$ s$^{-1}$. The contour interval is $5 \times 10^{-6}$ s$^{-1}$. Hatched areas are greater than $5 \times 10^{-6}$ s$^{-1}$. Doubly hatched areas are less than $-5 \times 10^{-6}$ s$^{-1}$. 
there are some areas, for example to the east of New Guinea and to the northeast of the Philippines, where there seems to be some incompatibility between the clouds and the divergence fields and these will require some additional diagnostic studies. There are many obvious limitations on arguments attempting to justify the correlation between low-level convergence or high-level divergence and what is seen on the cloud picture. In particular not all clouds are forced by strong convergence at low levels and not all clouds have an outflow region at 200 mb. The calculated values of the divergences of between 10−5 and 10−8 s−1 for active regions which have admittedly been slightly smoothed, correspond quite closely with those reported by McBride and Gray (1980) for tropical weather systems, and by Palmen and Newton (1969) for mid-latitude circulations.

In summary, the compatibility of the large-scale divergence fields with observed cloudy and clear areas strongly suggests that the increased data network and the univariate optimum interpolation scheme are producing physically realistic wind analyses that can be used for diagnostic research studies.

Summary

A univariate optimum interpolation analysis scheme has been developed for operational and research use over tropical latitudes. Features of the scheme are its three-dimensional aspect, the choice of sigma as the vertical coordinate, the use of frictionally corrected surface synoptic data and a manual interaction facility for operational use. Assessment of the wind analyses by operational forecasters, by comparison with available subjective analyses, and by testing the fit of the data suggests that the objective product is skillful and reliable in defining the strength and location of synoptic-scale systems, and is comparable in skill to manual analyses. Moreover, large-scale divergence fields generated from the analysed winds seem physically realistic and highly compatible with observed cloudy and clear areas, thus indicating that the analysis method is assimilating the observations in a sensible way.

The method of analysis of the temperature and moisture fields closely resembles that of the winds, and is not described here. The observational errors and error correlations of the first guess fields for both dry bulb and dew-point temperatures are similar to those described by Bergman (1979) for temperature.

There are a number of future developments that will be made to improve the analysis system. These include, improved specification of the error variances and correlation functions, improvements to the data checking system and to the methods of handling surface observations, and the development of a variational adjustment step to blend the mass and wind fields.

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