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OBJECTIVE ANALYSIS OF CLIMATOLOGICAL FIELDS : RESULTS OF TEST ANALYSES USING A SUCCESSIVE CORRECTION METHOD

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ABSTRACT

The use of objective analysis techniques in climatological studies is reviewed and the properties of a widely used scheme, namely a successive correction method (SCM), are described in detail. A sensitivity study of an SCM with a Gaussian weight function is carried out using raw $1^{\circ} \times 1^{\circ}$ monthly mean global evaporation rates from the UWM/COADS atlas to provide the observation field. The results are used to suggest a set of parameters for the analysis of climatological fields which are being generated from ship meteorological reports in the COADS 1a dataset. The analysed fields are found to be most sensitive to the value of the influence radius on the last pass of the analysis, with the choice of background field and number of passes being of only secondary importance. A minimum value for the influence radius in the range 210 - 350 km, which is somewhat smaller than that used in several past analyses, is found to be appropriate in regions of high data density such as the North Atlantic. The possibility of reducing the amount of noise in the analysed field by imposing a threshold on the number of observations required to generate a mean is investigated but is found to be impractical at a grid scale of $1^{\circ} \times 1^{\circ}$ as too much information is lost from the observation field. Finally, the integrated characteristics of the analysed field are found to be insensitive to the level of interpolation in the SCM which suggests that this is not an important factor in the context of heat budget calculations.

1.INTRODUCTION

The global distribution of *in situ* reports of surface conditions contained in marine databases such as the Comprehensive Ocean-Atmosphere Dataset (COADS, Woodruff et al., 1987) is strongly non-uniform. In regions such as the North Atlantic and North Pacific which contain the major shipping lanes the density of reports is high. However, other areas for example much of the South Pacific and the Southern Ocean are very data sparse. Even within a relatively data rich region such as the North Atlantic there are significant areas on scales of several degrees for which no reports are available in a given month. Consequently, the development of surface flux climatologies from *in situ* reports has required some degree of interpolation and smoothing to be carried out in order to fill in regions for which there are no observations and to reduce noise in areas of low sampling frequency. The aim of the current study is to review interpolation procedures that have been used in the past and to assess in detail the characteristics of analysed fields obtained with a particular successive correction method. The results will be used to determine an appropriate set of parameters for use in the generation of a global surface flux climatology from reports contained within COADS 1a (Woodruff et al , 1993).

Various approaches to the problem of data sparseness have been taken in the past. Bunker (1976) avoided having to carry out an interpolation in producing his flux climatology of the North Atlantic by using an irregularly shaped grid and increasing the size of the grid cells in data sparse areas in order to achieve a sufficient number of observations to form a mean (the size of the cells that he used varied from $1^{\circ} \times 1^{\circ}$ to $2^{\circ} \times 5^{\circ}$). Isemer and Hasse (1987) followed a similar approach in producing their revised version of the Bunker atlas but went on to transform the values in the irregularly shaped regions onto a regular $1^{\circ} \times 1^{\circ}$ grid using a two-dimensional, quadratic polynomial interpolation.

A more sophisticated objective analysis technique was employed by Levitus (1982) in producing his climatological atlas of the world ocean (which includes fields at a variety of depth levels as well as at the surface). This scheme is a successive correction method (SCM) of the type developed by Cressman (1959), in which the analysed field at a particular point is given by the sum of a background field at that point and the weighted mean of the differences between all observed values within a specified radius of influence and the background field at their respective locations. The analysis is repeated several times with the background field for each iteration being provided by the analysed field from the previous one and the radius of influence being reduced on each pass in order to restore information at successively smaller scales. On the first pass the background is given by an appropriate first-guess field, a zonal average in the case of Levitus (1982). The weight function used in formulating the mean of the differences contains a dependence on the distance of each observation from the analysed point and Levitus makes use of a Gaussian function of the type suggested by Barnes (1964).

A simplified version of this analysis, with a zero background field and only a single pass, i.e. a simple weighted mean of the observations within the radius of influence was employed for the climatology produced by Esbensen and Kushnir (1981). More recently, essentially the same Barnes type SCM as that used by Levitus has been employed in the production of the UWM/COADS flux atlas (da Silva et al., 1994). Of other recent climatological studies Oberhuber (1988) employed a filtered set of meteorological fields prepared by Wright (1988) and Hsiung (1986) appears not to have required any interpolation given the coarse scale ($5^{o} \times 5^{o}$) of her grid.

As a first approach to the problem of objective analysis we will make use of the established Barnes type SCM. The main aim of the sensitivity study described in this paper is to determine the most appropriate set of parameters for use with this scheme. In carrying out the objective analysis, choices have to be made regarding the number of passes and the influence radius on each, the background field and whether or not a threshold number of observations must be exceeded in order for a raw mean to be accepted for the observation field. The values for each of these parameters are considered in this sensitivity study.

The successive correction method is described in detail in the next section. Results from a sensitivity study of the method using a dataset consisting of globally gridded $1^{o} \times 1^{o}$ monthly raw means of the evaporation rate derived from COADS 1a by da Silva et al (1994) are presented in Section 3. In the final section, some conclusions are drawn and a set of parameters for use in producing the forthcoming climatology is suggested.

2. SUCCESSIVE CORRECTION METHOD

The details of the successive correction scheme developed by Cressman (1959) are presented in this section (see for example Thiebaux and Pedder (1987) for further discussion). The basic assumption of the scheme is that the difference between analysed field values on successive passes is well represented by a weighted sum of the differences between observed and analysed values at nearby locations. Hence, if $X^{a(k)}$ represents the value of the analysed field at a particular location on the kth pass then the corresponding value on the (k+1)th pass is given by

$$X^{a(k+1)} = X^{a(k)} + \sum h_j^{(k+1)} (X_j^{o} - X_j^{a(k)})$$

where the sum is over all grid points for which there are observations (i.e. raw mean values in the analysis treated here) within a region of influence of radius, R, about the analysed point, and X_j^{o} and $X_j^{a(k)}$ are the observed value and the analysed value on the kth scan at each grid point. For the first pass of the analysis $X^{a(0)}$ is given by the supplied first-guess field. The term $h_j^{(k+1)}$ is the value of a distance dependent weight function at the location of the jth grid point, note that the superscript, k+1, allows for the possibility that the weight - function may change between iterations. Various weight functions have been suggested, the one which has found widespread use in climatological analyses is that of Barnes (1964)

$$\begin{aligned} h_j(r_j) &= \frac{\exp\,(-4r_j^2 \;/\; R^2)}{\sum(\exp\,(-4r_j^2 \;/\; R^2))} \quad , \quad r_j \le R \\ &= \;\; 0 \qquad\qquad\qquad\qquad\quad , \quad r_j > R \end{aligned}$$

where r_j is the distance of the jth grid point from the point to be analysed and the sum is again over all grid points with observations within the radius of influence.

In the version of the above scheme used in the Levitus and UWM/COADS atlases there are four passes of the analysis with R = 1541, 1211, 881 and 771 km respectively. In addition, the analysed fields are smoothed after each pass, with a linear filter in the Levitus atlas analysis and a combination of non-linear and linear filters for the analysis used in the UWM/COADS atlas (termed the 'UWM analysis' hereafter). Levitus introduced the linear filter in order to remove discontinuities that arise in the analysed field between data rich and data sparse regions. The smoothing process has been extended to include a non-linear filter in the UWM/COADS atlas in an attempt to reduce the amount of noise at scales of one or two grid points. In both atlases it is noted that the response function (amount of damping of features of a given wavelength) for the analysis is not significantly changed (i.e. less than 5% difference) when the smoothing is included. In the UWM analysis, the analysed fields are first smoothed with a nine-point non-linear filter for which the smoothed value at a particular grid point is the median value of the nine points in a 3x3 region centred on it. This is followed by two passes of a five point linear filter (Shapiro, 1970) for which if $X^{NL}_{i,j}$ denotes the value of the analysed field at grid point (i,j) after the application of the non-linear filter, the smoothed value after the first pass is

$$X^{L}_{i,j} = X^{NL}_{i,j} + \frac{\alpha}{4}(X^{NL}_{i-1,j} + X^{NL}_{i+1,j} + X^{NL}_{i,j-1} + X^{NL}_{i,j+1})$$

On the first pass, the smoothing parameter α=0.5 and on the second -0.5, note that smoothed values from the first pass are used in the second. The resulting smoothed fields provide the background for the next pass of the analysis.

3. SENSITIVITY STUDY.

In this section, the characteristics of the raw mean field are considered and the results of objective analyses with a range of SCM parameters are discussed.

3.1. Dataset and Grid Characteristics

Global raw monthly mean evaporation rates on a 1 degree grid for January 1986 from the UWM/COADS atlas (da Silva et al., 1994) have been used for the observation field in the sensitivity study. They are shown in Fig.1, note that one observation was considered sufficient to define a raw mean in their analysis. Several features are evident : maxima in the evaporation rate of order 2-3 mm/(3hrs) over the Gulf Stream and Kuroshio, a zone of relatively high evaporation rate in the Trade Wind zone stretching from W Africa to the Caribbean (a feature which is also evident in the Bunker atlas (Isemer & Hasse, 1987)), and minima along the Pacific seaboard, over the Grand Banks and in the upwelling region off the coast of SW Africa. Large regions of the South Pacific, the whole of the Southern Ocean and the Northern Hemisphere oceans north of 60° N contain virtually no mean values.

The number of observations used to generate each 1 degree raw mean is shown in Fig.2 and listed in Table 1. Note that over 50% of the mean values are determined from 2 or fewer reports, and only 14% from 10 or more. Imposing a threshold of 10 observations to define a mean would restrict the area for which data is available to the mid-latitude North Atlantic, the Mediterranean and certain narrow shipping lanes over the rest of the world ocean.

The analyses of the raw evaporation rate field described below have been carried out on a 1° x 1° grid spanning the globe from 85° N to 85° S, within which each grid value is considered to be representative of the centre of that particular cell. The grid points are located at the intersection of the half degree lines of latitude and longitude.

3.2. Results of Analyses

Analyses of the January 1986 dataset have been made with various choices for the parameters of the SCM. The focus has been on the determination of appropriate values for the influence radius in data dense and data poor regions, and an examination of whether the use of the analysed field from the previous month as a background provides any advantage over a simple zonal average. The possibility of reducing noise in the analysed field by imposing a threshold on the number of observations required for mean generation has also been considered.

Table 1. Distribution of Number of Reports Used to Calculate the 1° x 1° Raw Means in the January 1986 Dataset

Number of reports used for mean	Number of cases	Percentage of cases
1	4900	34.8
2	2339	16.6
3	1385	9.8
4	1017	7.2
5	762	5.4
6	602	4.3
7	433	3.1
8	373	2.7
9	321	2.3
10	251	1.8
> 10	1688	12.0

3.2.1. Choice of Influence Radius

There are conflicting views as to how small the influence radius should be allowed to become in the analysis procedure. If the minimum value is too large, significant spatial variations in the observation field may be suppressed. Making it smaller increases the degree of resolution but at the same time allows observation errors to have a greater influence on the interpolation resulting in a noisier analysed field. Thiebaux and Pedder (1987) suggest that a lower limit on the influence radius is given by the mean separation between observations and from a cross-validation analysis of meteorological data find that a value between 1.5 and 2.5 times the mean separation results in the best analysed field. In contrast, Levitus (1982) argues that the minimum influence radius should be about 7-8 times the mean separation in order to avoid noise at shorter wavelengths. However, in regions with a well defined front on a scale of 2-3 grid points such a constraint would clearly result in a loss of information in the analysed field.

In order to study the characteristics of the analysed field with varying values for the influence radius, the UWM analysis described in Section 2, with a global zonal average as a first guess, has been carried out on the January 1986 evaporation rate field and the analysed fields output at the end of each pass (Figs. 3a-d). Two additional passes with R = 551 and 331 km (i.e. 5° and 3° in latitude) and the same smoothing filters as used in the UWM analysis have also been made in order to study the validity of taking R down to a smaller value in data rich regions such as the North Atlantic (Figs 3e-f).

The amount of structure in the analysed field increases with each pass of the SCM as the influence region for the analysis is restricted to successively smaller scales. Some of these features appear to be spurious, for example the areas of strong evaporation that develop in the South Pacific and the Agulhas region (although the latter may represent a real eddy feature that has become overamplified in the analysis), arising because the influence radius used is too small to allow strongly biased raw mean values to be damped by nearby unbiased values. In order to prevent such anomalies developing only the first two passes of the analysis were used for the region south of 40° S in the production of the UWM atlas. However, the existence of a significant number of anomalies in the data sparse region of the Pacific between the equator and 40° S after the fourth pass of the analysis (Fig.3d.) suggests that the above constraint is insufficient and that it should be applied to this region as well.

Fronts between regions of high and low evaporation e.g. the Gulf Stream / Grand Banks boundary become more clearly defined with the increasing resolution at small R. This is more apparent in Figs.4a-d which show enlarged views of both the raw mean and analysed fields after each of the last three passes in the North Atlantic. A comparison of Figs. 4a and d suggests that taking a minimum value of R=331 km may be justified in such a highly sampled region. In contrast, the analysis of the region of locally high evaporation off the coast of West Africa down to R = 331 km results in a feature with detailed structure and it is not clear whether this is an accurate representation of the true field or simply the result of overanalysis in a data sparse area; an analysis to 771 or 551 km may be more appropriate here.

The mean separation between the raw mean values in the January 1986 field over the North Atlantic has been calculated to be 139 km which indicates that the suggested minimum influence radius of 331 km is reasonable given the Thiebaux & Pedder criterion of 1.5 - 2.5 times the mean separation (209 - 348 km in this case) as a lower limit. Of course the distribution of raw means over the North Atlantic is not uniform and in heavily sampled regions, such as the Gulf Stream area, a reduced lower limit could be used in future studies of seasonal and interannual variability.

3.2.2. Choice of Threshold for Mean Generation.

In an attempt to reduce the number of spurious anomalies generated by the analysis in data sparse regions, the extended analysis described above was carried out on several subsets of the 1/86 raw mean field for which a threshold on the number of observations required to calculate a mean had been imposed. In doing this it was hoped that the reduced spatial coverage would be outweighed by the fact that the dataset now consisted of a more reliable set of means. Thresholds of 2 and 3 observations to define a mean were used and the raw fields in each case are shown in Figs. 5a-b. Comparison of these figures with Fig.1 shows that the imposition of a 2 observation threshold reduces coverage significantly in the Southern Hemisphere oceans although the primary features in the Northern Hemisphere are still fairly well represented. With a 3 observation threshold, the situation is worsened and very little information remains in the Southern Hemisphere.

The analysed fields for the 2 observation threshold dataset are shown in Figs. 6a-f. Comparison with the analysed fields obtained with no threshold (Figs. 3a-f) shows a reduction in the number of anomalous features in the Southern Hemisphere oceans, particularly the South Pacific ; the analysis for the Northern Hemisphere is essentially the same in both cases. However, other anomalies have survived the threshold, e.g. the Agulhas feature, and now grow more rapidly, reaching a greater spatial extent than previously, as the number of 'damping' means in the influence region around them has been reduced. The analysed fields obtained with a 3 observation threshold (not shown) have similar characteristics, with the Agulhas feature still surviving the threshold and growing more rapidly than before. It would seem that the more rapid development of those spurious features which are not removed by the threshold, coupled with the overall loss of information, limits the use of such constraints as a means of noise reduction and a better approach would probably be to increase the grid cell size in the data sparse regions.

3.2.3. Choice of Background Field

In the analysis described above a global zonal average, with 3-point smoothing between adjacent zones and interpolation to zones without any means, was used to provide the background field, shown in Fig.7a. However, this rather simple choice results in the analysed fields being dominated by global zonal features in the early stages of the analysis which are not a good description of the actual situation. Clearly it is desirable to use a background field which already contains the principal characteristics expected of the observations. Several choices are possible including the long - term climatological mean and the analysed field from the previous month. One advantage of using the previous month's field is that it should improve the representation in the analysis of anomalous features that persist over several months as opposed to spurious features which arise from biased ship reports in a given month.

In order to assess the advantages of using the previous month's field the analysis of the January 1986 dataset described in Section 3.2.1. has been repeated using a two pass analysis (R=1541 and 1211 km) of the December 1985 field as a background, the latter field is shown in Fig. 7b. and is clearly a better first guess in terms of representation of the main climatological features than the simple zonal average. Note that this field contains several features which differ from those in the analysis of the January 1986 dataset obtained with a zonal background field (compare with

Fig.3b), specifically the region of high evaporation in the sub - tropical North Atlantic is shifted westward and a strong anomaly is seen in the Eastern Indian Ocean. The analysed fields are shown in Figs. 8a-f. Comparison with the fields in Fig.3 shows that although the influence of the alternative choice for the background may be seen on the first pass in terms of a clearer definition of features such as the Gulf Stream and Kuroshio, and reduced zonality in general, it quickly fades thereafter so that by the fourth pass the two analysed fields (Figs. 3d and 8d) are essentially the same. This suggests that the choice of background field is not a primary factor in determining the characteristics of the final analysed field. It may be that the number of passes used in the analysis is too large as the effective weight given to the observations increases while that for the first-guess field decreases with each pass (Thiebaux & Pedder, 1987). However, a repeat analysis with just two passes at R = 1211 & 331 km results in a field with virtually identical characteristics to the one obtained with the full six pass analysis. This suggests that the R-values on the intervening passes are less important than those on the first and last pass for determining the field characteristics.

3.2.3. Sensitivity of Zonally Averaged Fields to SCM Parameters.

The sensitivity of the zonally averaged and basin integrated evaporation rates to the level of interpolation used in the SCM analysis has been investigated using a subset of the analysed fields described in the previous section for the Atlantic. The variation of the zonally averaged evaporation rate with latitude after passes 1, 3 and 6 of the analysis of the 1/86 raw mean field with the 12/85 two-pass analysis as a background is shown in Fig. 9a. The zonal average is most sensitive to the level of interpolation in the data sparse regions north of 50^{o} N and south of 30^{o} S as one would expect given the lack of observations in these regions. However, in the data rich intervening region, 50^{o} N - 10^{o} N, and in the relatively data poor band between 10^{o} N and 30^{o} S, the zonal average is essentially independent of the level of interpolation.

Of more interest from the point of view of the contribution of evaporation to the overall freshwater budget (and via the latent heat flux to the heat budget) is the basin integrated rate. The integrated evaporation rate north of a given latitude is shown in Fig.9b and is seen to be essentially independent of pass number. This suggests that the redistribution of information by the SCM doesn't have a significant effect on the integrated characteristics of the field and hence that the level of interpolation is not an important parameter for budget calculations.

4. DISCUSSION

The characteristics of analysed fields obtained with an empirical objective analysis scheme, namely a successive correction method with a Barnes weight function have been assessed in order to determine a suitable set of parameters for the production of a surface flux climatology from *in situ* reports. The observation field consisted of $1^{o} \times 1^{o}$ gridded raw evaporation rates for January 1986 from the UWM/COADS atlas (da Silva et al., 1994). As a first approach, the parameters used in the UWM analysis were employed. The analysed fields were found to give a reasonable representation of the main observed features in data dense regions but also to introduce an undesirable amount of noise in data sparse regions north of 40^{o} S such as the SE Pacific (south of 40^{o} S the number of passes of the analysis is constrained in order to reduce the amount of noise). The minimum influence radius used in the UWM analysis is 771 km. However, the mean grid point separation in data dense regions such as the North Atlantic is of order 140 km which, based on the cross-validation analyses of Thiebaux and Pedder (1987), would suggest that a minimum radius of influence in the range 210 - 350 km would give a better analysed field. Extended analyses were carried out with influence radii equal to 551 and 331 km and these show a clearer definition of features in data dense regions than is obtained with the UWM analysis without introducing extra noise.

Various choices for the background field to the analysis have been investigated but this parameter appears to have only a limited influence on the analysed field. In particular, use of the previous month's analysed field as a background rather than a simple zonal average results in a less zonal field in the early stages of the analysis but subsequently the two analysed fields become virtually identical. An attempt was made to reduce the number of spurious features which develop in data sparse regions by imposing a threshold on the number of observations required in order to generate a monthly mean. However, given the fine scale of the grid, this inevitably resulted in the loss of a large amount of information even with thresholds of just 2 or 3 observations and the consequent reduction in damping by surrounding observations gave rise to more rapid amplification of the remaining noise. It is clear that the coverage provided by in situ reports is insufficient to generate monthly means on a 1° x 1° grid in the data sparse regions of the world ocean and a better approach may be to bin the data on a larger scale in such regions.

Based on the results of this study we suggest the parameters in Table 2 for the objective analysis of the raw flux fields produced in the climatology project.

Table 2 . Suggested SCM Parameters for Use in Global Flux Climatology

Radius of influence on successive passes	1541, 1211, 771, 331 km
Number of passes	2 (85 - 65° N, 40 - 85° S) 3 (0° - 40° S) 4 (0° - 65° N)
Background field	Previous month's 2-pass analysis
Grid resolution	1° x 1°
Threshold for mean calculation	None
Smoothing	Non-linear + linear (as UWM)

The basic scheme is similar to that applied in the Levitus & UWM/COADS atlases, the major difference being in the level to which the fields are analysed, the choice of 331 km as a minimum influence radius should provide a better description of the data rich areas than is found in their analysis. The inclusion of a dependence of the number of passes on latitude is a crude attempt to allow for the variations in the spatial distribution of observations although these are not strictly zonal and at this stage seasonal variations have not been considered. As regards the background field, it may be better to use the monthly climatology for the period 1980-92 rather than the field from the previous month's analysis as suggested here, however this is unlikely to make a large difference given the insensitivity of the scheme to the background.

Finally, note that the parameters of the bulk formulae used for the flux calculations will be tuned using an inverse analysis of the ocean heat transport calculated from the analysed climatological fields constrained against values from hydrography. With this in mind, the sensitivity of the zonally averaged and basin integrated evaporation rates to the level of interpolation has been studied and found to be not significant. Hence, the degree of interpolation is unlikely to be an important parameter for heat budget calculations.

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FIGURES

(Note that the colour palette shown on Fig.1 has been used for all of the other global maps except that shown in Fig.2)

Fig.1) $1^{\circ} \times 1^{\circ}$ Raw Mean Evaporation Rate Field for January 1986 from the UWM / COADS Atlas. Units, mm/3hr interval.

Fig.2) Number of Observations Used to Form the $1^{\circ} \times 1^{\circ}$ Raw Mean Evaporation Rate Field for January 1986.

Fig.3) $1^{\circ} \times 1^{\circ}$ Analysed Mean Evaporation Rate Field for January 1986 After Consecutive Passes of the Successive Correction Method with a Zonal Mean Background Field a.) R = 1541 km ; b.) 1211 km ; c.) 881 km ; d.) 771 km ; e.) 551 km ; f.) 331 km.

Fig.4) Detail of the Raw and Analysed Mean Evaporation Rate Fields for January 1986 in the North Atlantic a.) Raw Field ; b - d.) Analysed Field After Pass at 771 km, 551 km and 331 km.

Fig.5.) $1^{\circ} \times 1^{\circ}$ Raw Mean Evaporation Rate Field for January 1986 from the UWM / COADS Atlas with a Threshold of a.) 2 Observations ; b.) 3 Observations to Define the Mean.

Fig.6) $1^{\circ} \times 1^{\circ}$ Analysed Mean Evaporation Rate Field for January 1986 After Consecutive Passes of the Successive Correction Method with a Zonal Mean Background Field a.) R = 1541 km ; b.) 1211 km ; c.) 881 km ; d.) 771 km ; e.) 551 km ; f.) 331 km. A threshold of 2 observations to define a mean has been applied to the raw field.

Fig.7) Background Fields : a.) Zonal Average for January 1986 ; b.) Analysed Field for the Previous Month (December 1985) After Two Passes of the SCM With R=1541 and 1211 km.

Fig.8) $1^{\circ} \times 1^{\circ}$ Analysed Mean Evaporation Rate Field for January 1986 After Consecutive Passes of the Successive Correction Method with the December 1985 Two Pass Analysed Field as a Background a.) R = 1541 km ; b.) 1211 km ; c.) 881 km ; d.) 771 km ; e.) 551 km ; f.) 331 km.

Fig.9a.) Zonal and b.) Basin Integrated Evaporation Rate in the Atlantic for January 1986 After Analysis Passes at 1541 km (short - dashed line), 881 km (dash - dot) and 331 km (solid). December 1985 Two Pass Analysed Field Used as a Background.

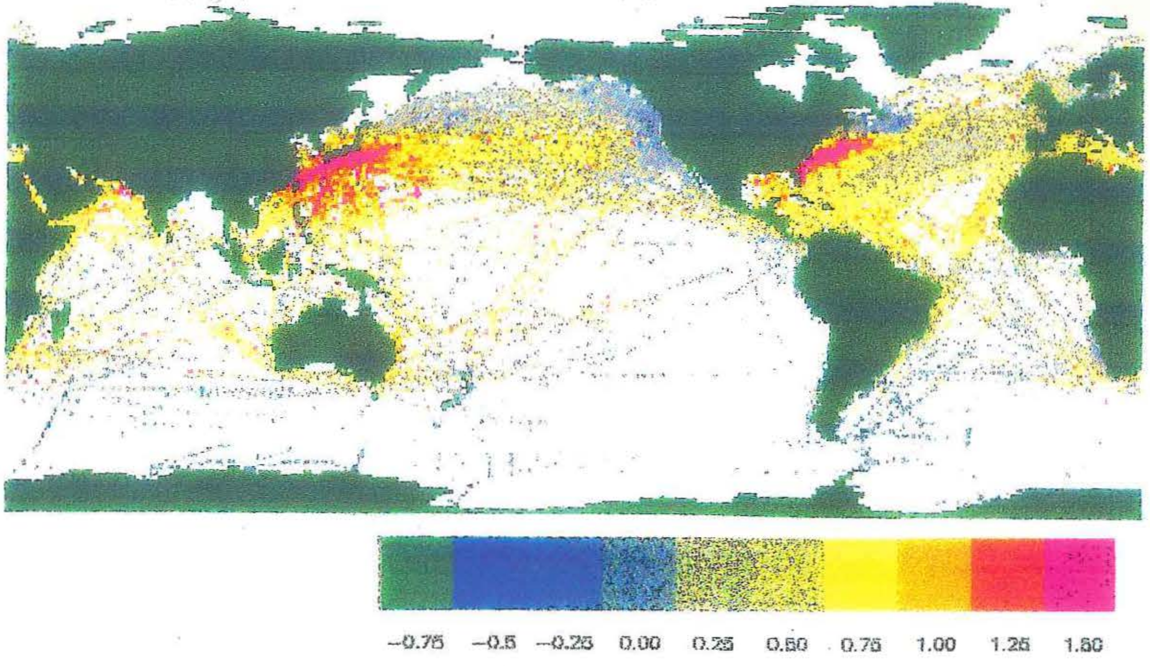


Fig.1) 1° x 1° Raw Mean Evaporation Rate Field for January 1986 from the UWM / COADS Atlas. Units, mm/3hr interval.

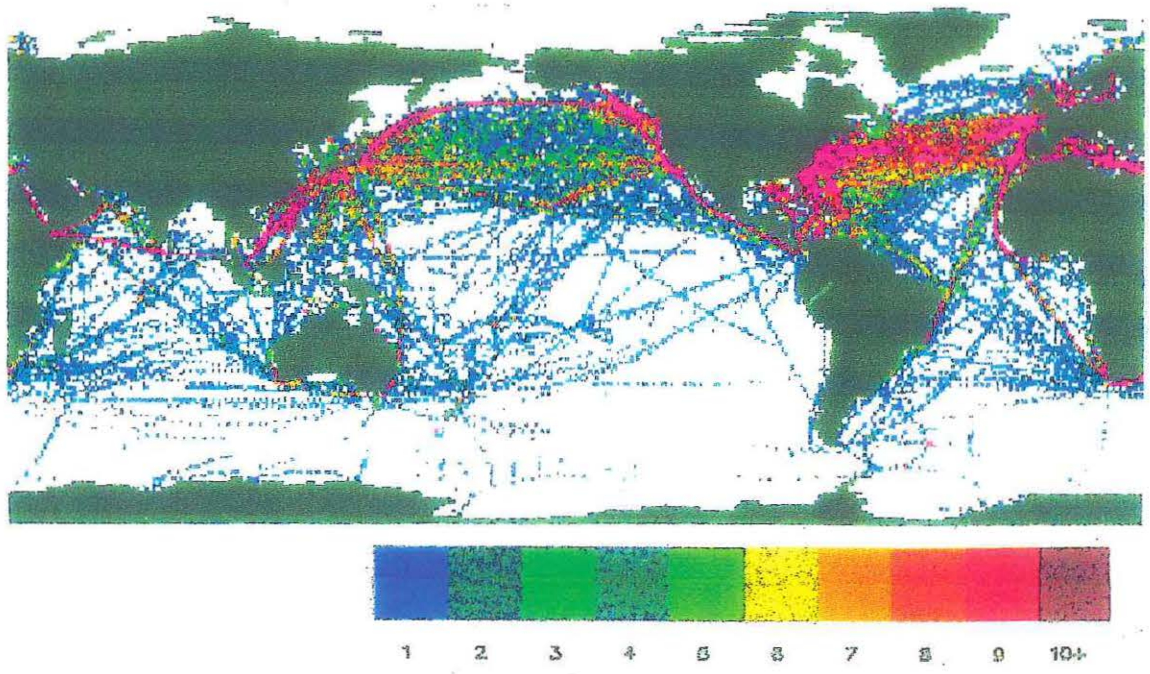
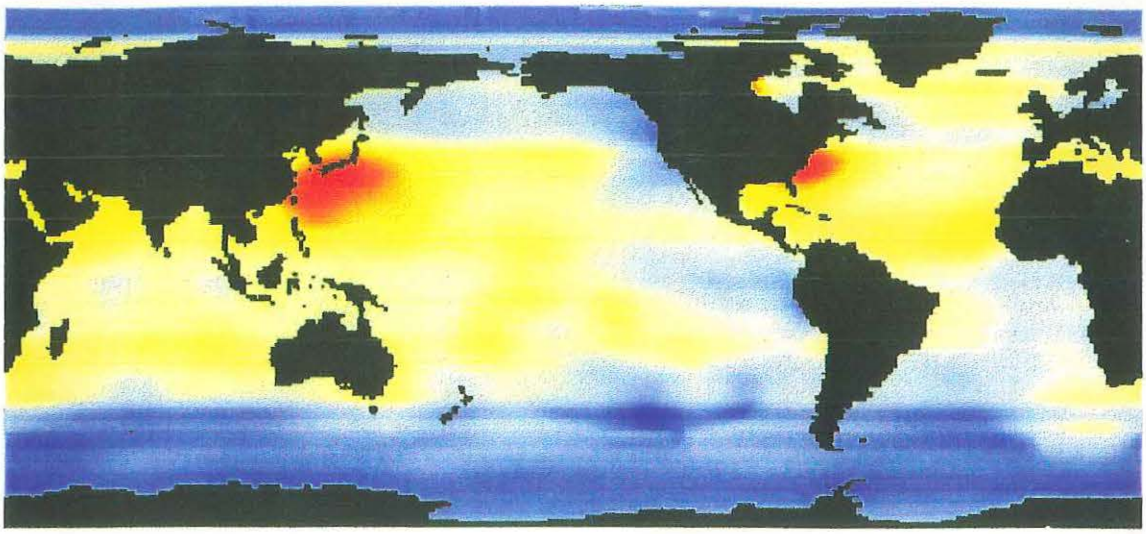


Fig.2) Number of Observations Used to Form the 1° x 1° Raw Mean Evaporation Rate Field for January 1986.

Fig.3) $1^{\circ} \times 1^{\circ}$ Analysed Mean Evaporation Rate Field for January 1986 After Consecutive Passes of the Successive Correction Method with a Zonal Mean Background Field a.) R = 1541 km ; b.) 1211 km ; c.) 881 km ; d.) 771 km ; e.) 551 km ; f.) 331 km.

a)



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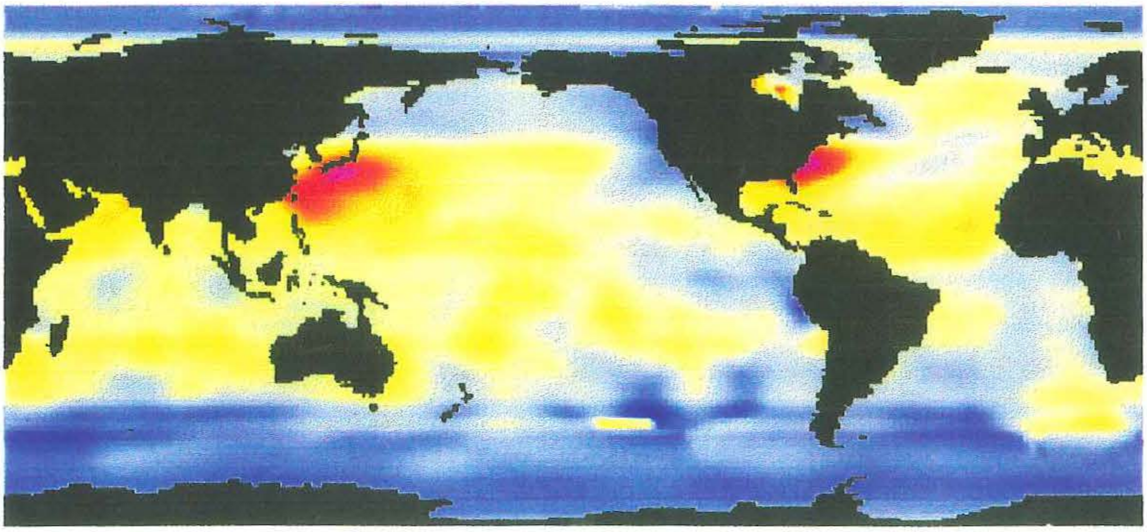
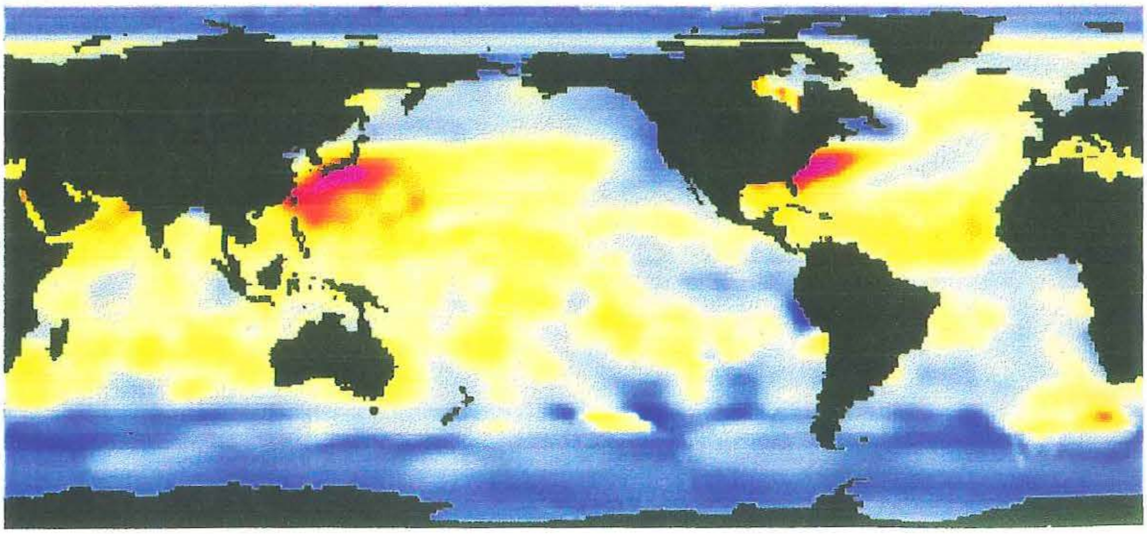
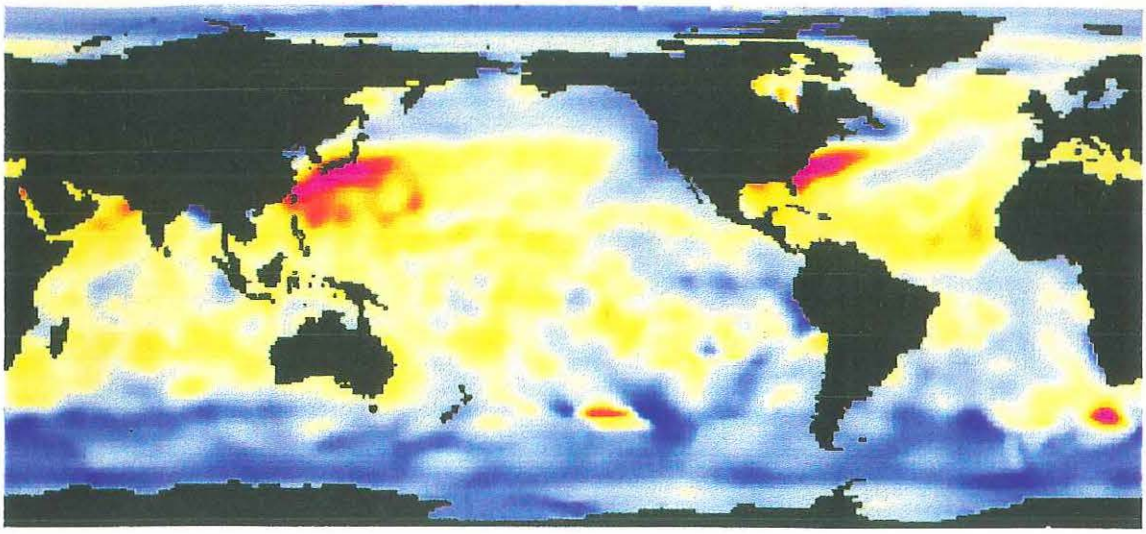


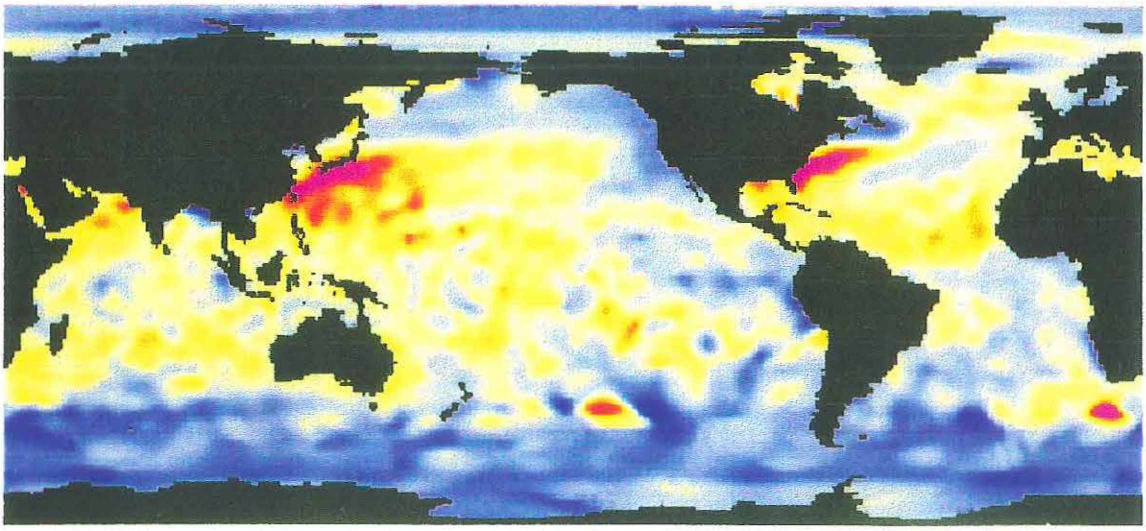
c)



d)



e)



f)

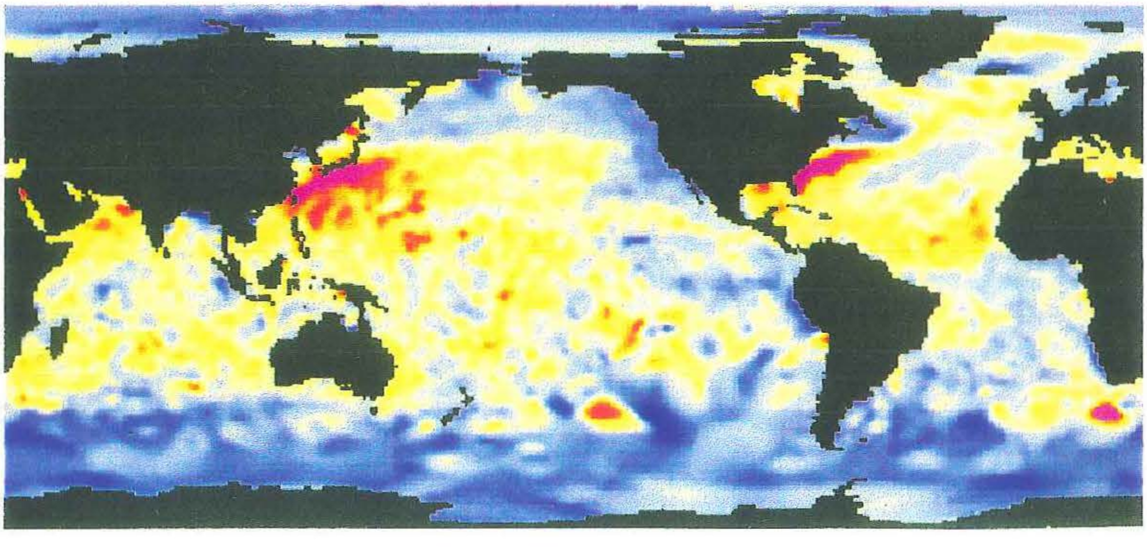
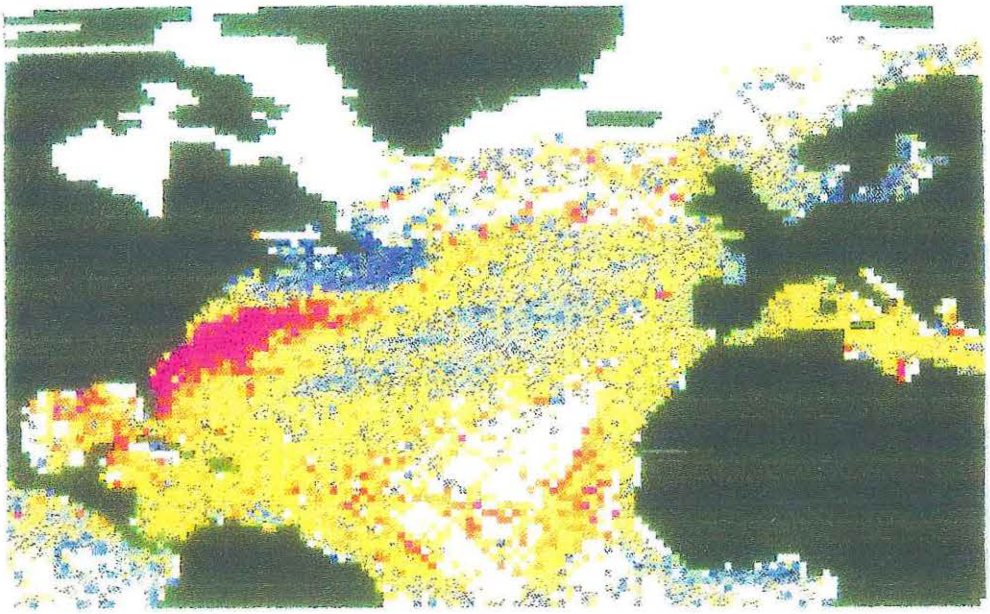
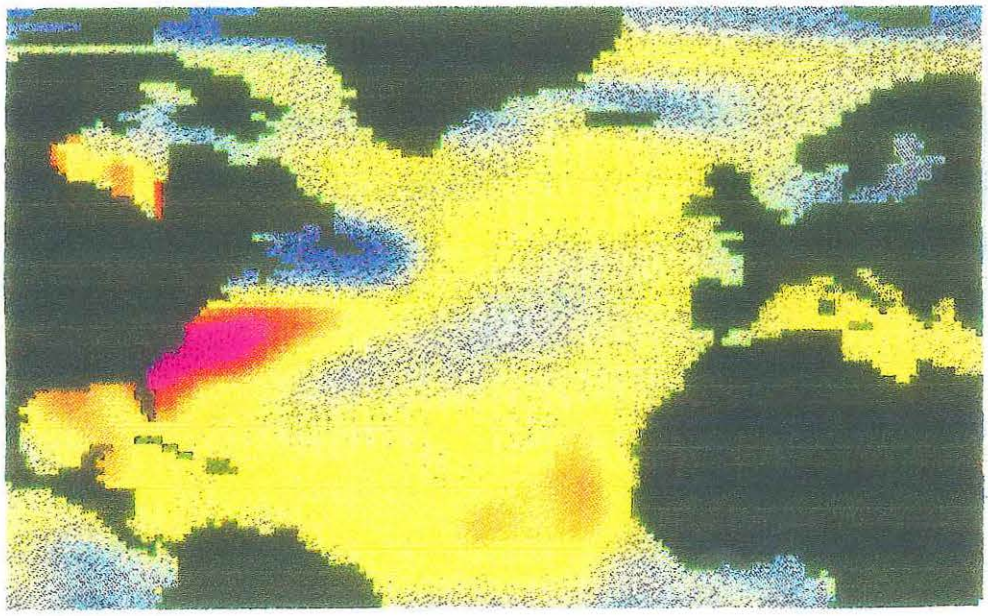


Fig.4) Detail of the Raw and Analysed Mean Evaporation Rate Fields for January 1986 in the North Atlantic a.) Raw Field ; b - d.) Analysed Field After Pass at 771 km, 551 km and 331 km.

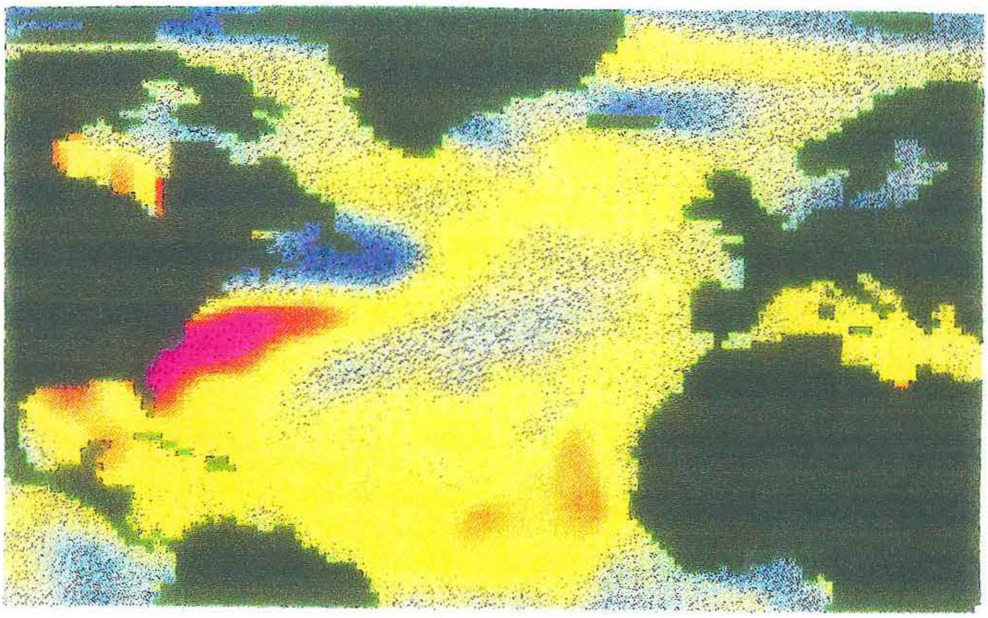
a)



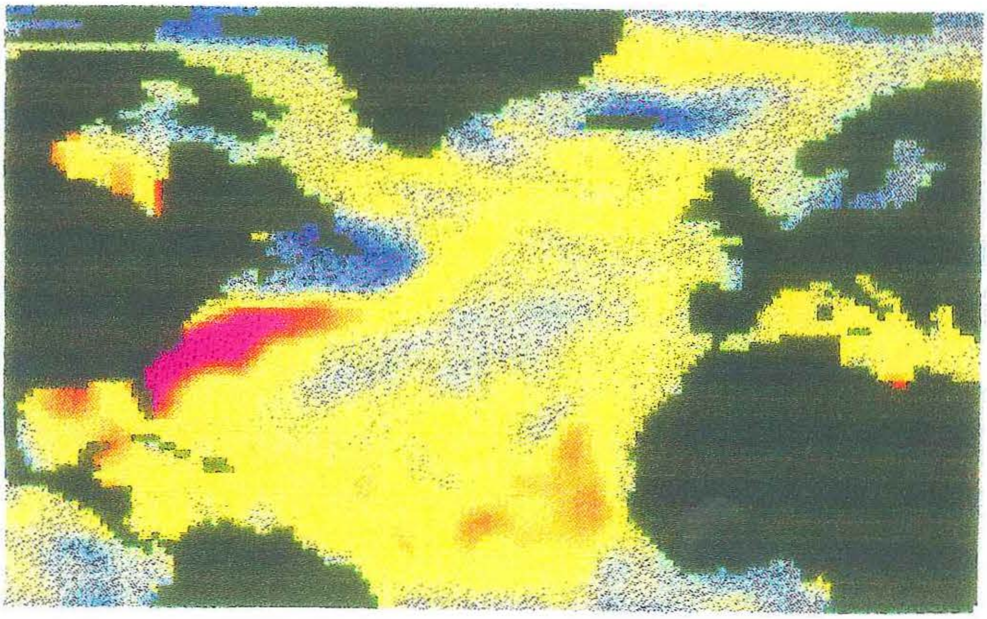
b)



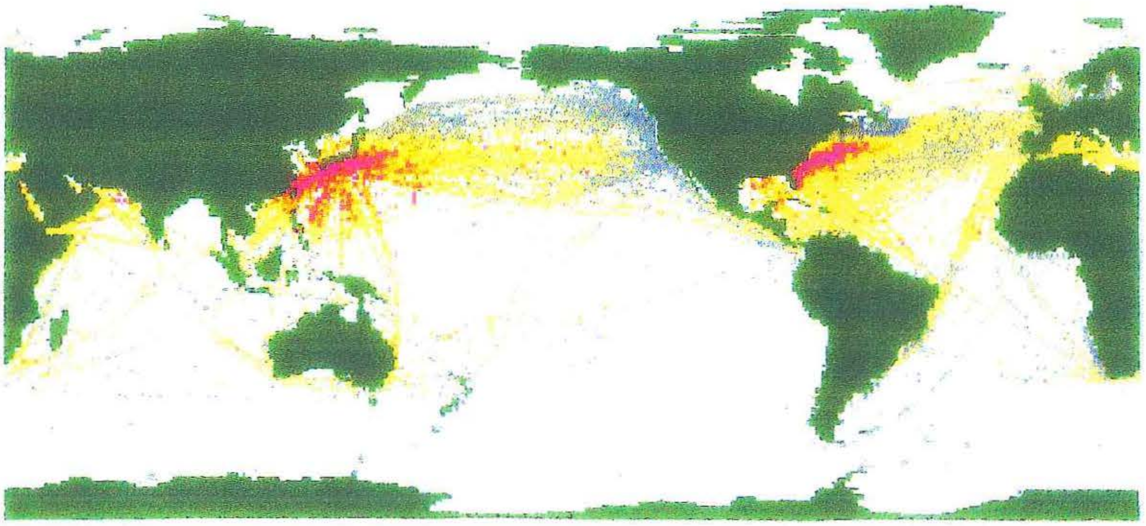
c)



d)



a)



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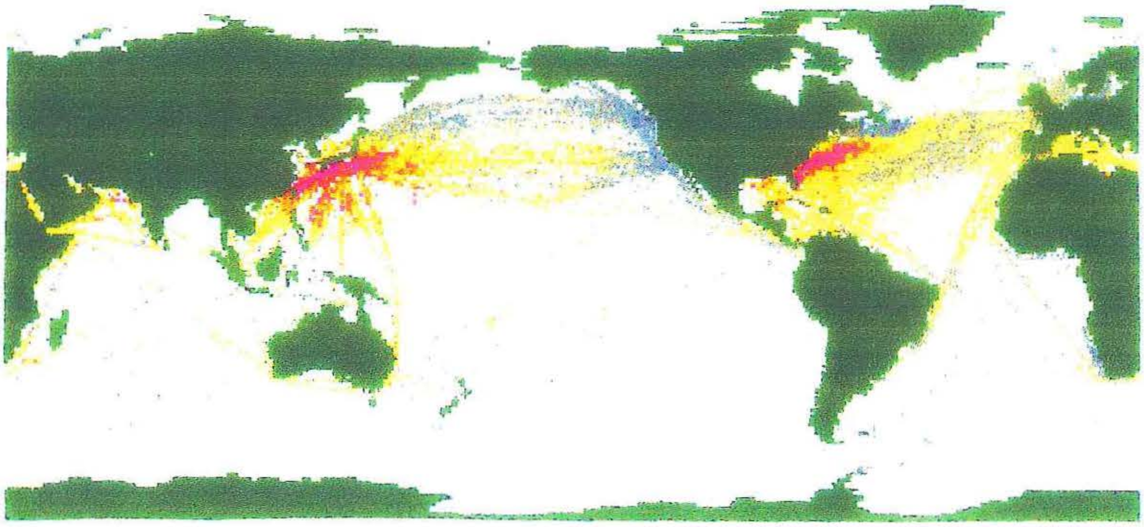
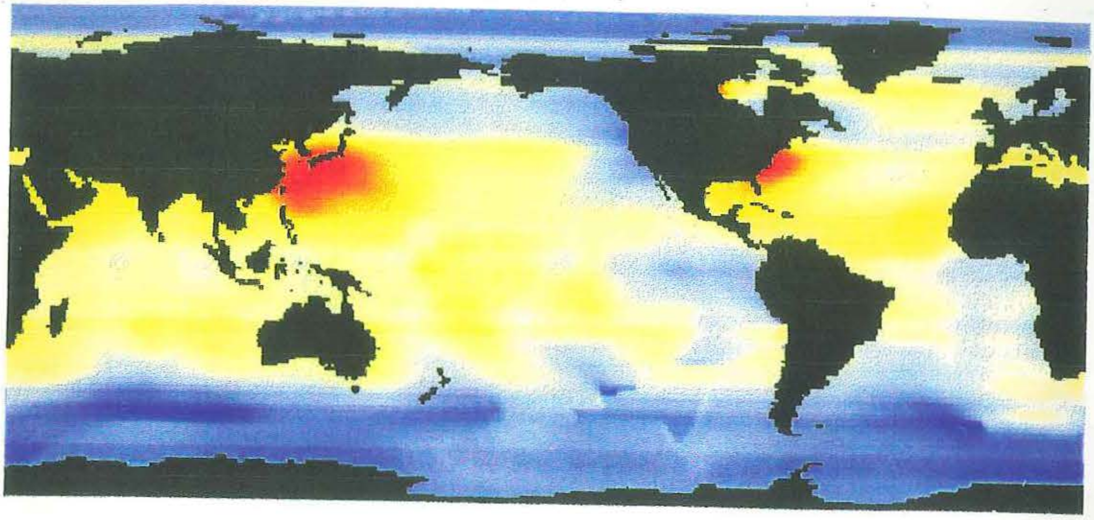


Fig.5.) $1^{\circ} \times 1^{\circ}$ Raw Mean Evaporation Rate Field for January 1986 from the UWM / COADS Atlas with a Threshold of a.) 2 Observations ; b.) 3 Observations to Define the Mean.

Fig.6) $1^{\circ} \times 1^{\circ}$ Analysed Mean Evaporation Rate Field for January 1986 After Consecutive Passes of the Successive Correction Method with a Zonal Mean Background Field a.) R = 1541 km ; b.) 1211 km ; c.) 881 km ; d.) 771 km ; e.) 551 km ; f.) 331 km. A threshold of 2 observations to define a mean has been applied to the raw field.

a)



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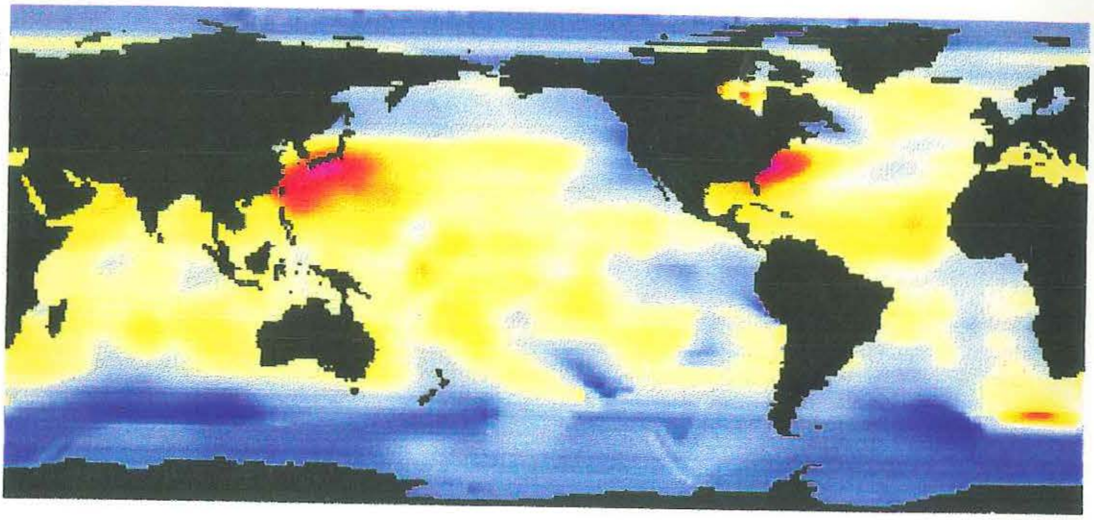
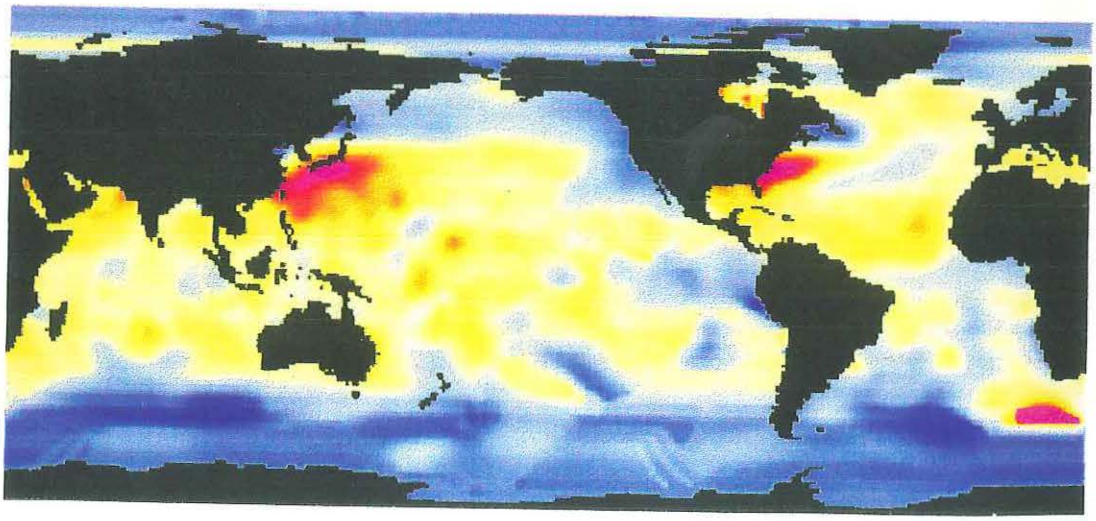


c)



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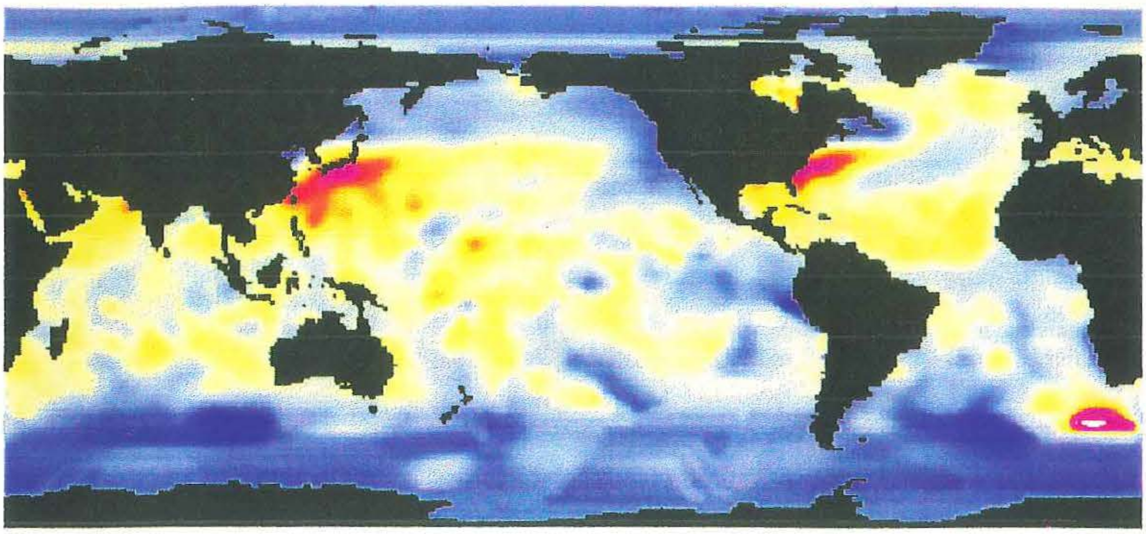
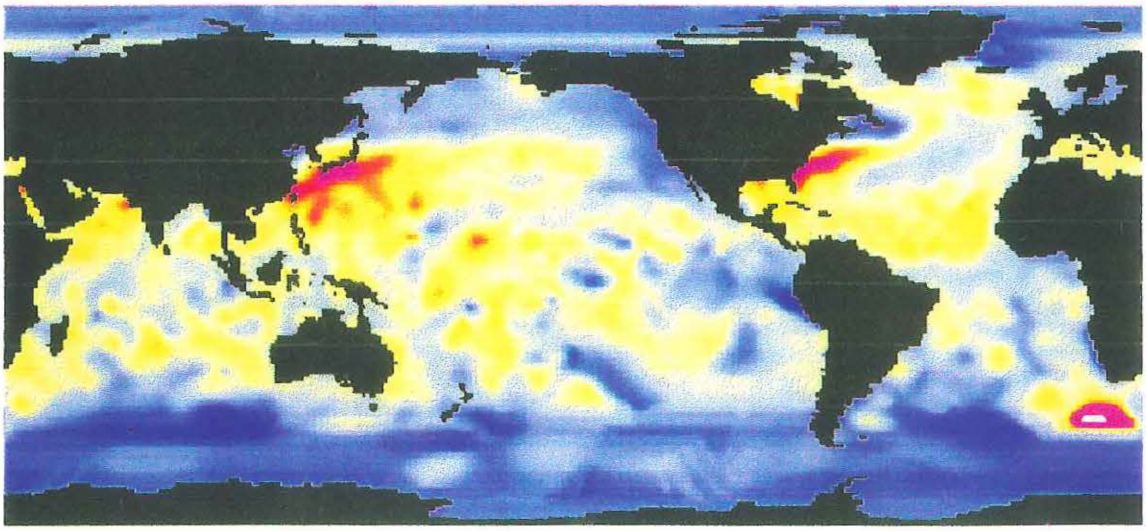
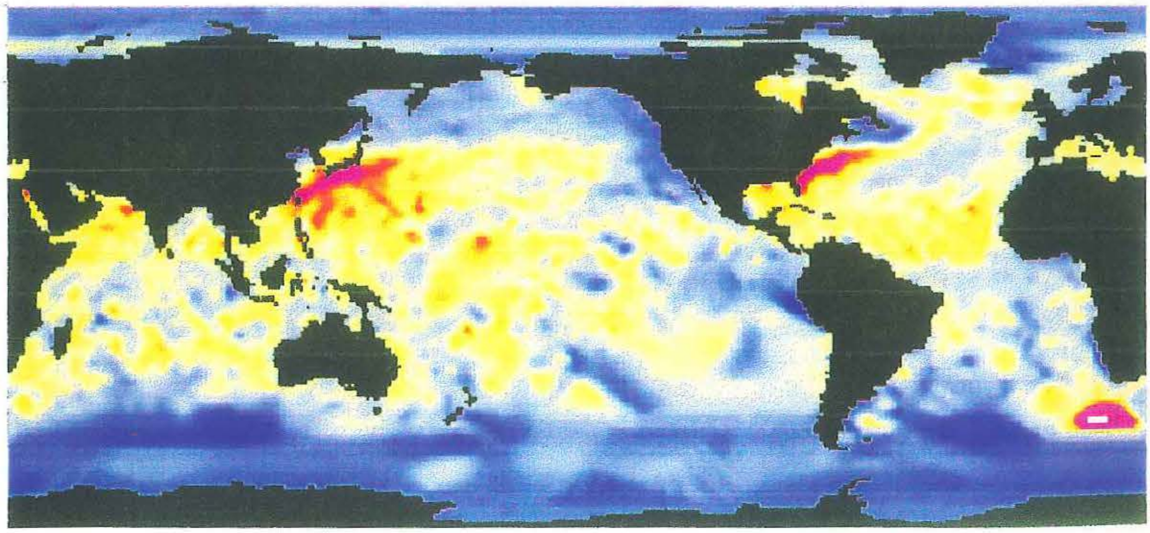
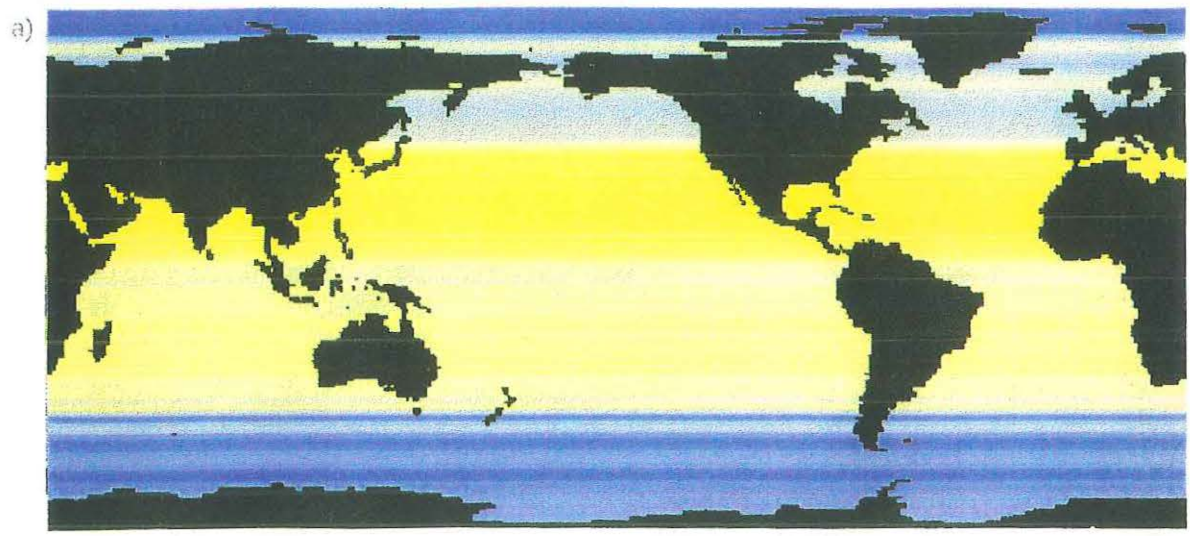


e)



f)





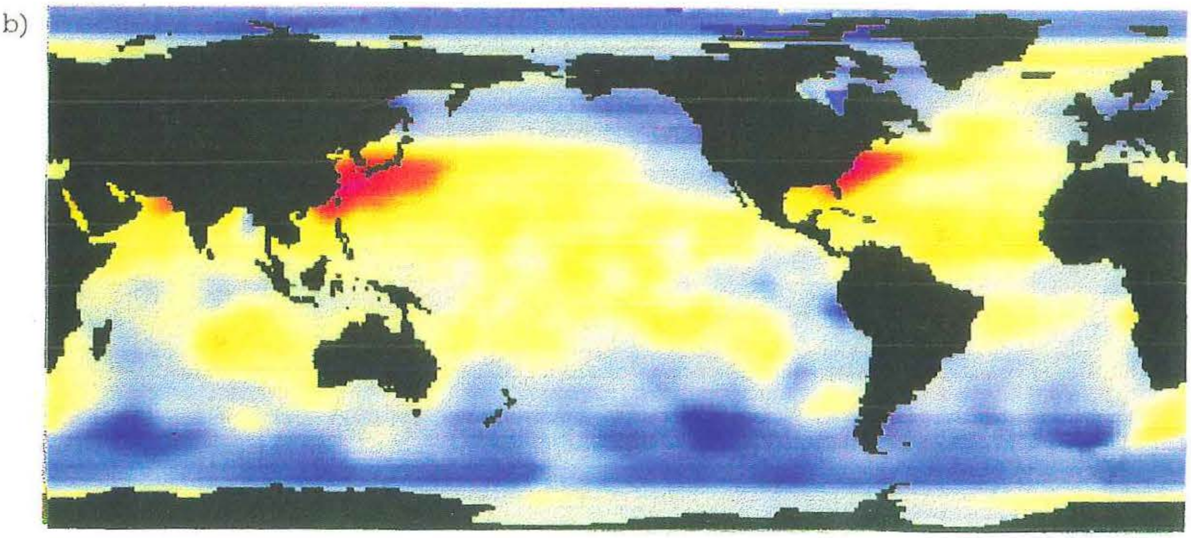


Fig.7) Background Fields : a.) Zonal Average for January 1986 ; b.) Analysed Field for the Previous Month (December 1985) After Two Passes of the SCM With R=1541 and 1211 km.

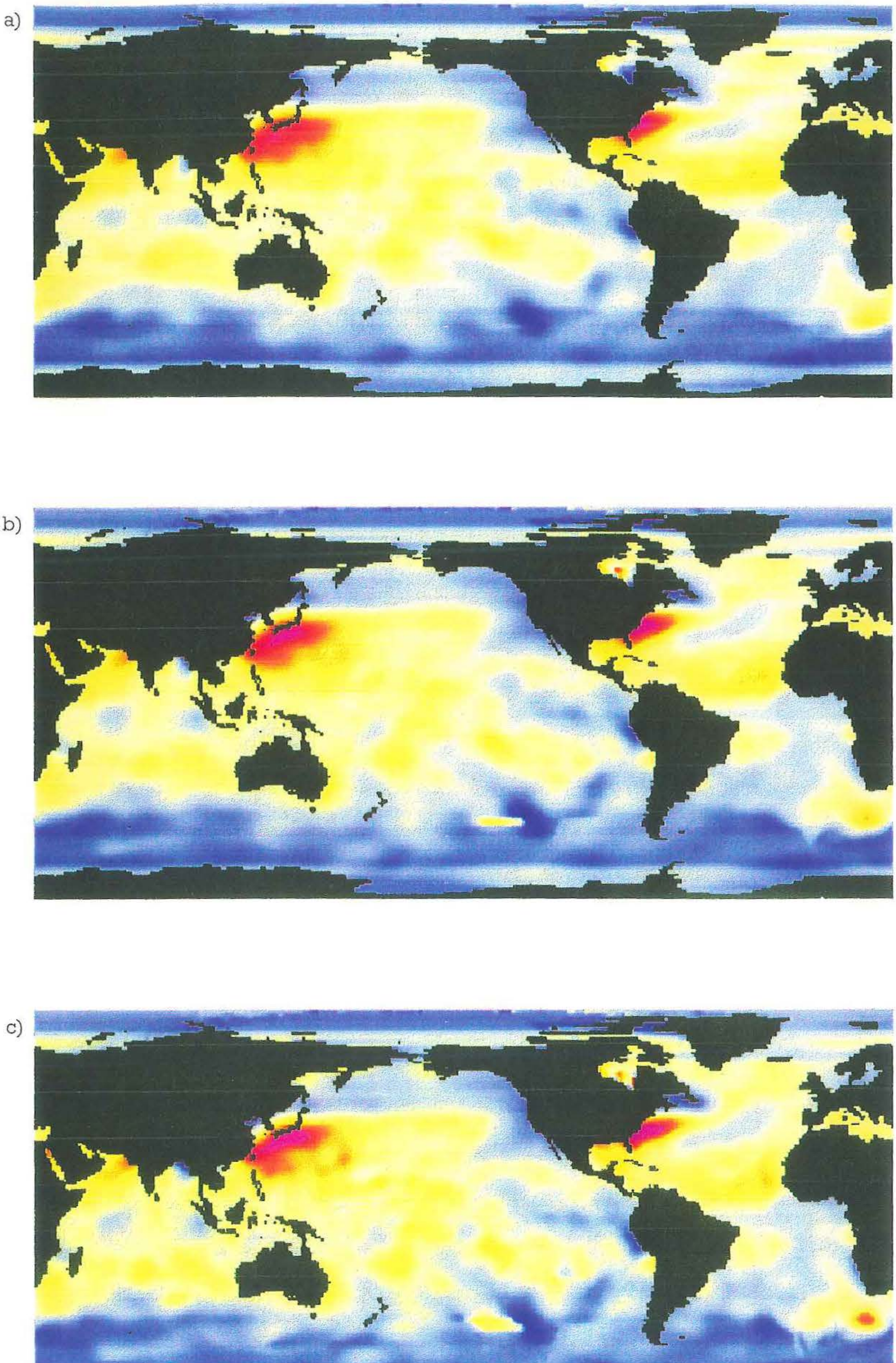
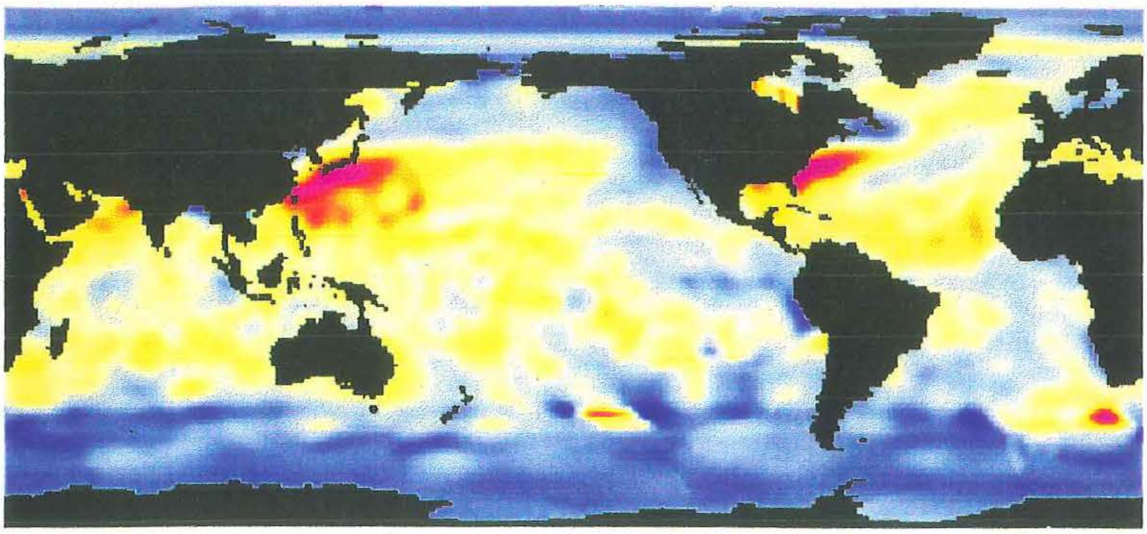


Fig.8) $1^{\circ} \times 1^{\circ}$ Analysed Mean Evaporation Rate Field for January 1986 After Consecutive Passes of the Successive Correction Method with the December 1985 Two Pass Analysed Field as a Background a.) R = 1541 km ; b.) 1211 km ; c.) 881 km ; d.) 771 km ; e.) 551 km ; f.) 331 km.

d)



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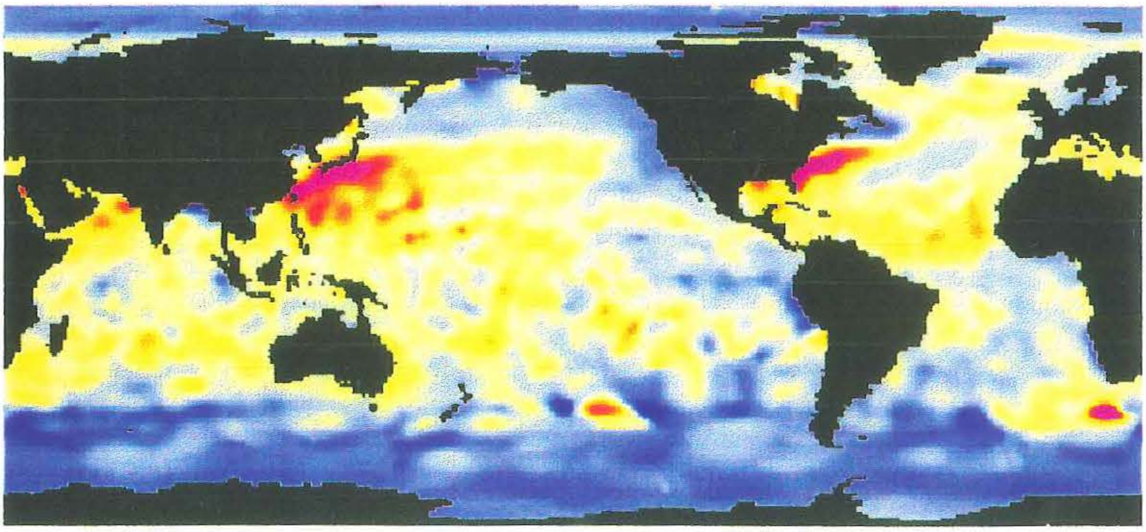
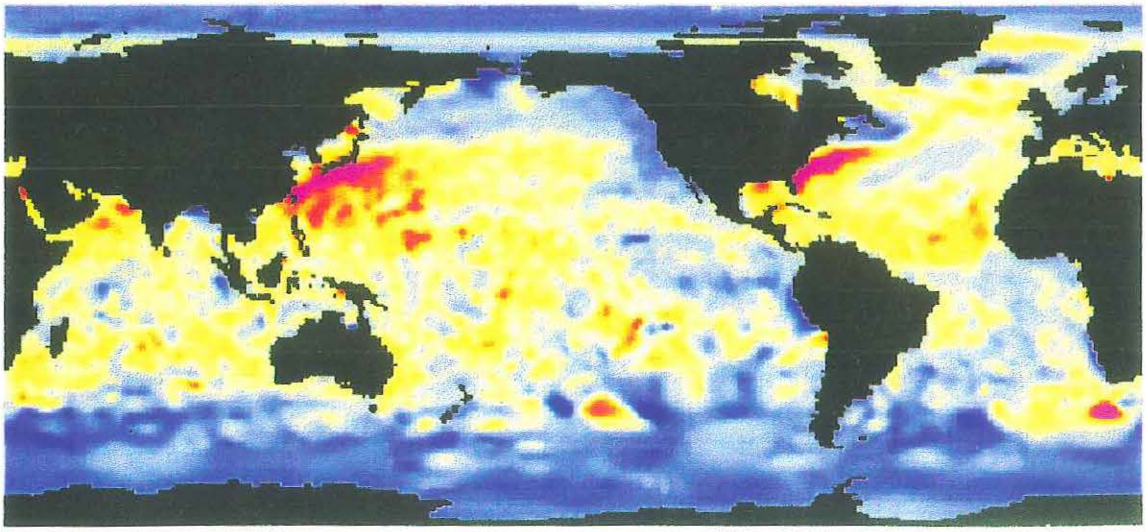


f)



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