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PREDICTIONS OF PRECIPITATION FROM TWO GLOBAL CIRCULATION MODELS AND AN EMPIRICAL TECHNIQUE.

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ABSTRACT

Two sets of ensemble simulations have been run using different climate versions of the UK Meteorological Office (UKMO) Atmosphere Global Circulation Model (AGCM) over the common period 1979-1990. Both ensemble sets are forced with simultaneous observed Sea Surface Temperature (SST). One ensemble set consists of short (4 month) runs using atmospheric initial conditions observed near the start of the season to be simulated, while the other set is taken from long term (1949-93) AGCM runs with no real atmosphere input. Precipitation predictions by the AGCMs have been assessed by comparison with observations and compared with a set of statistical linear regression forecasts using two SST predictors related to El Nino / Southern Oscillation events (ENSO).

The two sets of simulations and the regression predictions have significant skill. The AGCM simulations using beginning of season initial atmospheric conditions have highest skill, particularly in the first month of the season. There is considerable overlap in predictability between the AGCM ensembles but not much overlap between the AGCM simulations and the ENSO based regression predictions.

1. INTRODUCTION

The UK Meteorological Office has been issuing experimental real-time forecasts for seasonal rainfall for selected regions in the tropics since 1986, from preceding global scale sea surface temperature (SST) patterns using empirical techniques (Folland et al., 1991, Ward and Folland, 1991). Since 1994, information from an AGCM has been included in the real time forecasts. In this paper the potential predictability from such AGCMs is assessed globally by comparing modelled and observed rainfall for two seasons, December-January-February (DJF) and March-April-May (MAM).

2. THE C20C (Climate of 20th Century) SIMULATIONS

Rowell (1996) found useful potential predictability of tropical rainfall from an ensemble of six 45 year runs of the UKMO AGCM version HADAM1 forced with observed SST from the Meteorological Office Global Ice and Sea Surface Temperature (GISST1.1) dataset (Parker et al.,1995). The ensemble runs are distinguished from each other only by the use of different initial conditions at the beginning of the 45 year period. The initial conditions used were not the real ones for the start date of the run but were randomly selected from a series of analyses for the appropriate time of year. The only observed data input to these runs were the sea temperatures and ice coverage; no observed atmospheric or land surface data were used. These runs were made as part of the Climate of the 20th Century project and will be referred to henceforth as the C20C runs.

3. THE IC (Initial Condition) SIMULATIONS

More recently a set of AGCM runs have been carried out at UKMO as part of the PROVOST project (**PR**ediction **O**f climate **V**ariability **O**n **S**easonal and interannual **T**imescales), a joint project supported by the European Commission involving several European climate modelling centres (Evans and Evans, 1996). These runs differ from the C20C runs in that the model starts each season with the correct atmospheric conditions as well as being forced with simultaneous SST. Since these runs use atmospheric initial conditions, they are here referred to as the IC runs. These runs use the more recent HADAM2B version of the UKMO model. Compared with HADAM1, a number of small changes have been made (Hall et al., 1995). The most significant effects of these changes on the rainfall climatology are generally higher (more accurate) and smoother rainfall patterns over land, with reductions in rainfall in mountain areas due to reduced diffusion. Overall though, the rainfall climatologies of HADAM1 and HADAM2B are both similar to the observed globally complete Legates and Willmot (1990) climatology, (Hall et al.1995, Fig. 19).

The IC runs were made for boreal winters (December-February) and springs (March-May) over the period December 1979 - May 1990. The winter runs used atmospheric initial conditions from the end of November and the spring runs used initial conditions for the end of February. An ensemble of 9 runs were made for each season, the ensemble members being distinguished from each other through slightly different start times. The first winter run was started with initial conditions for 00Z 22nd November, the second run was started with initial conditions for 00Z 23rd November, the third used 00Z 24th November etc. The Spring runs were likewise initialised at 24 hourly intervals near the end of February.

The SST data used by the IC runs is slightly different to those used by the C20C runs over the period 1982-1990. Over this period, the IC runs use an SST dataset created by Reynolds and Smith. (1994) using Optimum Interpolation (OI). Data coverage over 1982-1990 is good so the two globally complete OI and GISST datasets are quite similar. GISST was made using smaller scale interpolation and is generally less smooth than the OI data. The largest differences occur south of 40S, well away from the main areas being considered in this study.

4. LINEAR REGRESSION PREDICTIONS USING ENSO-RELATED SST PATTERNS

The El-Nino Southern Oscillation cycle is widely documented as the most important source of interannual rainfall variability in the tropics. Ropelewski and Halpert (1987,1989,1996) identified tropical or sub-tropical regions all around the globe whose climate is affected by the ENSO cycle. ENSO predictors contribute to the forecasts of North African and NE Brazil seasonal rainfall issued by UKMO (Folland et al., 1991, Ward and Folland, 1991). For comparison with the AGCM results, linear regression precipitation forecasts were made for gridpoints worldwide over the same period as the AGCM runs using two ENSO related SST predictors. This was done to determine if the AGCMs could out perform a simple empirical forecast and to find out whether there is any link between AGCM predictability and predictability from ENSO. The predictors used were the time series of 2 global SST Empirical Orthogonal Functions (EOFs) representing phases of ENSO. The first predictor was the time series of the first EOF of High Frequency (HF) SST anomalies over 1901-90 (Fig. 1a). Prior to calculating the EOFs, HF data was created by filtering out interdecadal variability on timescales greater than 8 year so patterns clearly representing ENSO could be calculated without distortion due to low frequency variability and climate change. Unfiltered data was used to calculate the EOF time series (the series of dot products between the EOF pattern and the SST anomaly patterns). The positive/negative phases of this EOF represent El Nino/La Nina events. The second predictor (Fig. 1b) is the second EOF of high frequency SST anomalies. The positive/negative phases of this EOF represent SST early in a La Nina/El Nino event. The first and second EOFs are associated with 13 and 4% of the total SST variance respectively.

These predictions differ importantly from the AGCM simulations as they are genuine forecasts assessed on independent data. September-November SST observations are used to predict December-February precipitation and December-February SST are used to predict March-May precipitation. The regression equations were calculated over 1901-78 and tested over 1979-90. Since these predictions are based on El Nino, they are henceforth referred to as El Nino Regression (ENR) predictions.

5. VERIFICATION USING OBSERVED PRECIPITATION DATA

Hulme (1994) has made available to UKMO one of the best available datasets of observed monthly precipitation for land stations worldwide which have been gridded onto the same 2.5° latitude x 3.75° longitude grid used by the AGCMs. These data were used to assess the two sets of AGCM simulations and the ENR predictions. Due to the global scale of this study and to minimize noise, the rainfall simulations, predictions and observations were averaged to a 10° latitude x 15° longitude grid. Use of this grid results in almost complete coverage of all land areas outside the polar regions. However in data sparse areas such as centres of South America, Africa and Asia, the grid point values may only be based on just one station.

To measure skill, the correlation between the simulated or predicted precipitation and observed precipitation was calculated for every grid box and is referred to henceforth as "correlation". Using this measure eliminates the effects of local systematic bias in the model simulations. The correlation is not affected by the observed values having a different variance to the predictions.

TABLE 1 :NUMBER OF 10°x15° AREAS FOR WHICH THE FOLLOWING COMBINATIONS OF SIMULATIONS AND PREDICTIONS HAVE 5% SIGNIFICANT CORRELATION GLOBEWIDE, POISSON PROBABILITIES IN BRACKETS

Method Month\	IC total	C20C total	ENR total	IC & C20C	ENR & IC	ENR & C20C	ALL
DJF*	29	28	31	15 (.04)	7 (.03)	12 (.01)	6 (.00)
Dec*	40	20	23	7 (.00)	9 (.01)	6 (.01)	4 (.00)
Jan*	31	25	16	14 (.00)	7 (.00)	6 (.00)	5 (.00)
Feb*	21	30	22	10 (.00)	8 (.21)	11 (.00)	5 (.00)
March*	27	26	24	15 (.00)	6 (.07)	5 (.08)	4 (.00)
MAM	50	43	42	25 (.01)	16 (.45)	15 (.08)	9 (.01)
March	76	26	24	18 (.00)	9 (.06)	5 (.01)	4 (.00)
April	23	27	17	11 (.02)	4 (.05)	6 (.14)	3 (.00)
May	22	25	36	7 (.00)	7 (.05)	7 (.02)	5 (.00)

*IC runs for periods annotated with * use atmospheric initial conditions for the last 9 days in November, the remainder use initial conditions for the last 9 days in February. (Dec=December,Jan=January,Feb=February).*
Probabilities shown are the probabilities of the observed totals from the 2 or more methods given the observed totals from the individual methods listed in the 3 left-hand columns. Probabilities are calculated using the Poisson equation.

The two sets of ensembles and the regression predictions were assessed over the common period 1979-90. For assessing the simulations, the 9 member IC and the 6 member C20C ensemble means were used. Figs. 2 and 3 show the spatial distribution of Significant Correlation (SC) of the C20C and IC ensemble means and of the ENR predictions. Boxes where the correlation from at least 1 method is significant at the 5% level are shaded with a pattern dependent on what combination of methods have SC. Boxes for which predictions are made but no method has SC are blank. Numbers of boxes with each type of shading are listed in Table 1.

TABLE 2. AVERAGE CORRELATION FROM THE SIMULATIONS AND PREDICTIONS

	GLOBE			TROPICS (30N-30S)		
	IC	C20C	ENR	IC	C20C	ENR
DJF*	.18	.16	.10	.22	.19	.14
Dec*	.29	.06	.08	.20	.06	.12
Jan*	.13	.11	.07	.18	.15	.09
Feb*	.08	.12	.13	.13	.17	.16
March*	.07	.11	.09	.14	.17	.14
MAM	.19	.17	.13	.28	.24	.19
March	.34	.11	.09	.36	.16	.14
April	.08	.15	.05	.13	.19	.09
May	.08	.10	.13	.14	.12	.16

*IC runs for periods annotated with * use atmospheric initial conditions for the last 9 days in November, the remainder use initial conditions for the last 9 days in February.*

Simulations and predictions of precipitation totals for the 3 month seasons DJF and MAM were assessed along with simulations and predictions for the individual months. The results in Table 1 show that SC is much more extensive than expected by chance for most predictions.

6 . OVERALL DISTRIBUTION OF CORRELATION SKILL

For the period DJF (Fig. 2a), extensive areas of SC are found in the West Pacific and near the east coasts of America and Africa. This is the dry season in most of north Africa and south Asia so the lack of extensive SC here is less important. SC is most prevalent in the Tropics and sub-tropics, especially in coastal areas but is not prevalent in southern

South America, West Australia and South West Africa however. The individual month assessments for December (Fig. 2b), January (Fig. 2c) and February (Fig. 2d) show a similar distribution of SC, the most notable exception being the IC predictions for December which have extensive SC in the northern extra-tropics.

In MAM the ITCZ moves north near the Equator. The SC in March-May is less concentrated in particular areas but is generally more extensive than in DJF, particularly in Asia (Fig. 3a). Average correlation is generally higher for the MAM predictions than for the DJF predictions (Table 2). Only precipitation over land is assessed however and most of the ITCZ in DJF is over sea. Using analysis of variance, Rowell (1996) found that for the C20C runs, there is usually better agreement between the ensemble members in predicting rainfall over tropical ocean areas than in predicting rainfall over land. Similar results have been found for the IC runs. The individual month assessments for MAM show SC to be quite scattered but correlation is generally higher than for the DJF individual months. For both DJF and MAM and for all 3 methods, 3 month simulations or predictions are generally more skilful than single month simulations or predictions respectively.

7. THE EL-NINO REGRESSION PREDICTIONS

ENR SC is confined mainly to the west Pacific and Caribbean regions with some scattered SC elsewhere. ENR correlation is generally lower than AGCM correlation which is expected because the ENR predictions are based on SST observed in advance of the rainfall season, while the AGCM simulations are based on simultaneous SST and because ENR is based on just 2 predictor indices while the AGCMs use SST from all over the world. The locations of the significant ENR predictions correspond well with the results of Ropelewski and Halpert (1987,1989,1996). For example, DJF rainfall in North Brazil, South USA, the SW Tropical Pacific and SE Africa was linked to ENSO by Ropelewski and Halpert and was predicted with SC by ENR.

The number of areas with SC from ENR and at least one AGCM simulation (Table 1, 5th and 6th columns) was generally less than the number of areas with SC from both AGCM simulations (Table 1, 4th column) and not significantly higher than expected by chance in several months given the total number of areas with SC from each method (Table 1, 1st, 2nd and 3rd columns). The insignificant probabilities in the 5th and 6th columns of Table 1 suggest that in these months, much of the AGCM predictability is independent of ENSO and vice versa.

An interesting exception to the generally low ENR skill relative to the AGCM skill is in May when the ENR prediction skill becomes much more extensive than in previous months, particularly around the NW Atlantic and in Asia. In May ENR has higher average skill than the AGCM simulations inside or outside the Tropics.

8. IMPACT OF INITIAL CONDITIONS ON CORRELATION SKILL

The IC correlation is expected to be slightly better than the C20C correlation on average because of the use of correct atmosphere initial conditions. For December-February (Fig. 2a) the IC simulations do have marginally better correlation (table 2,average r=0.18) than the C20C simulations (r=0.16) or the ENR predictions (r=0.10). The correlation is higher when assessment is restricted to the tropics but the scores for the 3 methods are in the same order. The difference between IC and C20C correlation could be due to initial conditions or a superior model being used for the IC runs.

The assessment of December simulations (Fig. 2b) provides a strong clue to explaining the difference between IC and C20C correlation. The most notable difference between the DJF and December result is a substantially greater number of areas with SC from the IC simulations. This increased correlation for December relative to DJF can be attributed to the impact of relatively recent initial atmospheric conditions for the following reasons; a) no similar correlation increase is observed in the C20C simulations or ENR predictions which are entirely based on sea temperatures, b) the correlation increase is concentrated in areas where the correlations from C20C simulations or ENR predictions are insignificant. In fact the number of areas where there is SC from IC and from one or more of the other methods is reduced (Table 1). The IC correlation increase is concentrated outside the tropics; in the tropics, average correlation falls from 0.22 to 0.20 (Table 2).

In January (Fig. 2c) November initial conditions have less impact on IC correlation. IC is still has higher correlation than the IC simulations or ENR predictions however. In February (Fig. 2d) the IC correlation is much less than in January or December. In contrast correlation from C20C in February is generally has higher than correlation from IC in February or from C20C in December or January.

The simulations for March to May show a similar story. SC from IC is concentrated in March (Fig. 3b), when the late February initial conditions have most impact but IC correlation falls off quickly in April and May (Fig. 3c, 3d) while C20C shows a modest improvement in April and May relative to March. Also when March is simulated using atmosphere initial conditions for late November instead of for late February, correlation from the IC simulations is no longer higher than correlation from the C20C simulations (Fig. 4).

9. CONCLUSIONS

Precipitation simulations by 2 AGCMs were assessed alongside empirical precipitation predictions for 11 years . Conclusions from this study should be taken with caution as the period of assessment is shorter than ideal. The grid boxes used are large and it should not be assumed that if a grid box average is predictable then everywhere within the box is predictable. Precipitation observations for some of the boxes were sparse with the box means not always giving a very good indication of actual average precipitation within the box area. To check on how this problem may affect results, the study was repeated with 2.5^0 latitude x3.75° longitude boxes. While there were many local differences, conclusions a to e below also applied to the smaller grid boxes suggesting that the conclusions are to a certain extent, independent of box area size.

a) Both AGCM simulations and the ENR predictions have significant skill in predicting rainfall, especially in the Tropics. AGCM skill is generally a little higher than ENR skill.

b) There is some overlap in the distribution of prediction skill particularly in the tropical west Pacific. However most AGCM predictability is independent of the ENSO based regression predictions and vice versa, demonstrating (not surprisingly) that other SST patterns are important besides ENSO.

c) The IC predictions have slightly higher skill than the C20C predictions when predicting rainfall totals for 3 months but this difference in skill is concentrated in the first month and is probably due to the use of correct atmospheric initial conditions by the IC runs. There is no evidence from these results that one model was better than the other.

d) Over land areas, March-May predictions are better than December-February

e) May rainfall in the North Atlantic seems predictable from ENSO. Further research into this link is recommended.

This investigation may not have demonstrated all the precipitation predictability from the AGCM simulations or the ENR predictions. For example there may be significant skill in predicting a rainfall pattern over a wide area but insignificant skill in predicting rainfall for a region within this area.

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Figure 1(a): Global All seasons 1901–90 HF SST EOF 1

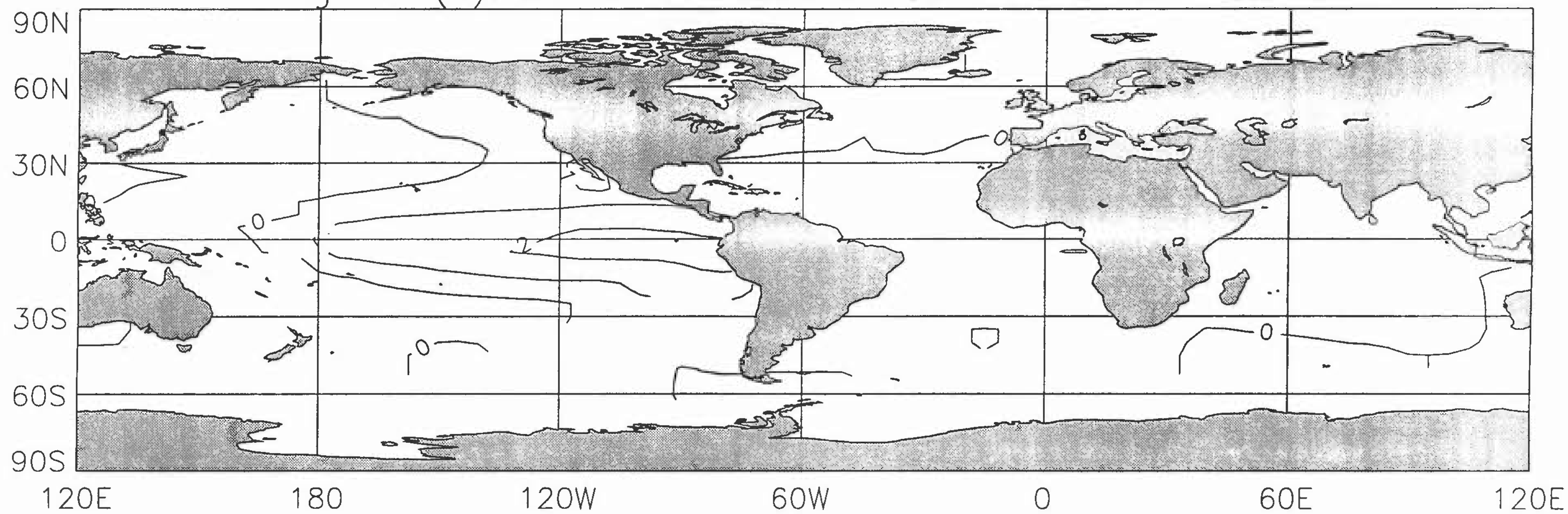

Figure 1(b): Global All seasons 1901–80 HF SST EOF 2

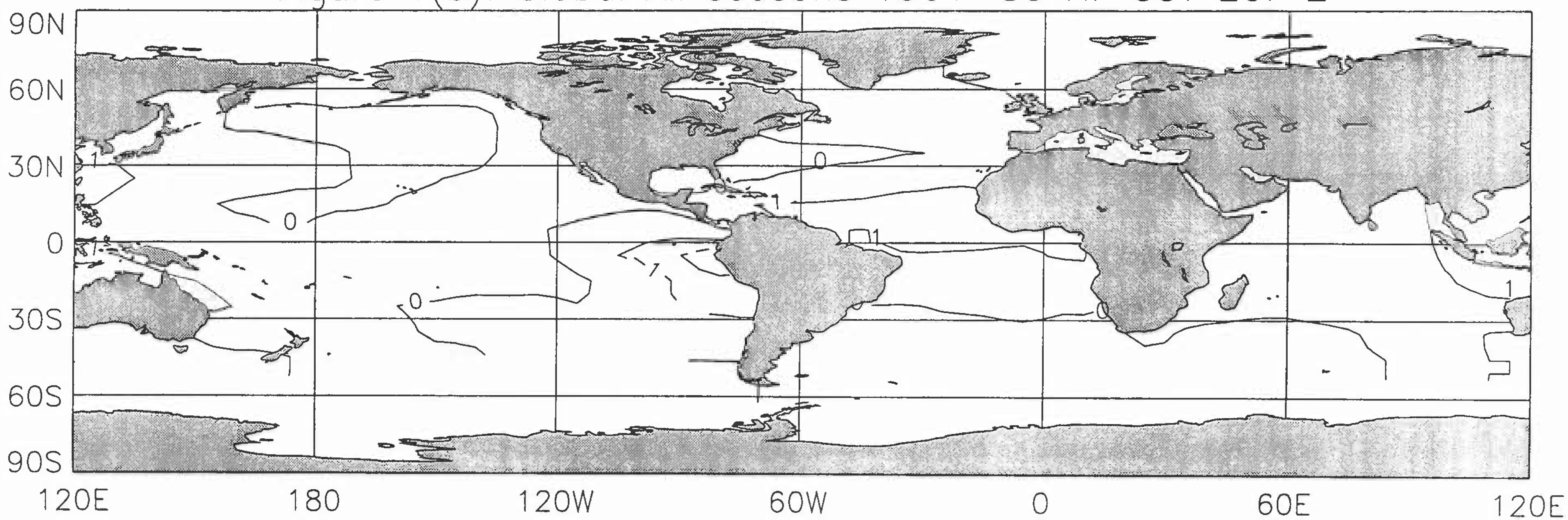

Figure 2: Comparison of 3 methods of predicting precipitation 1979/80–1989/90
Shaded boxes show where method(s) in key have 5% significant correlation skill

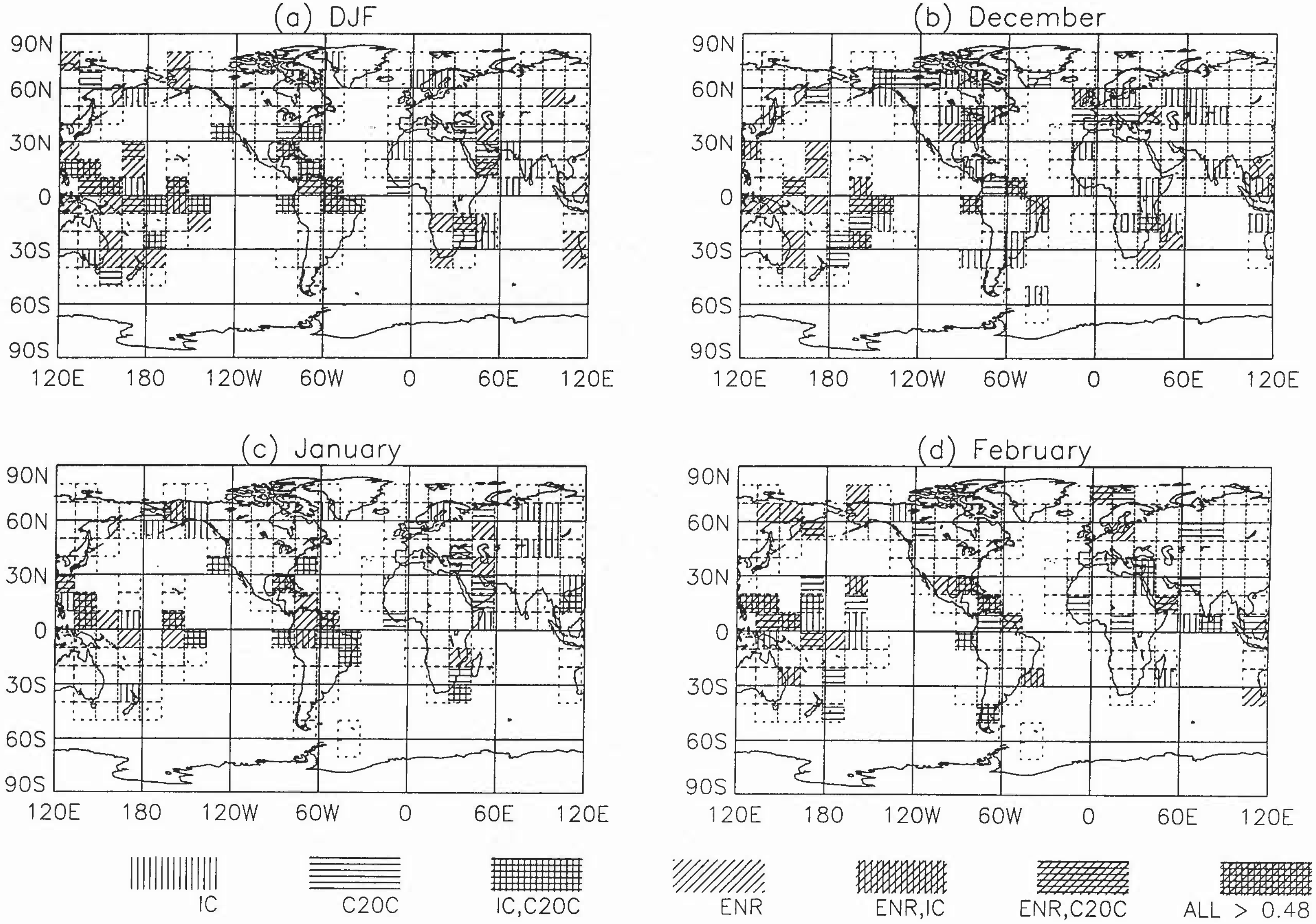

Figure 3: Comparison of 3 methods of predicting precipitation 1980–1990
Shaded boxes show where method(s) in key have 5% significant correlation skill

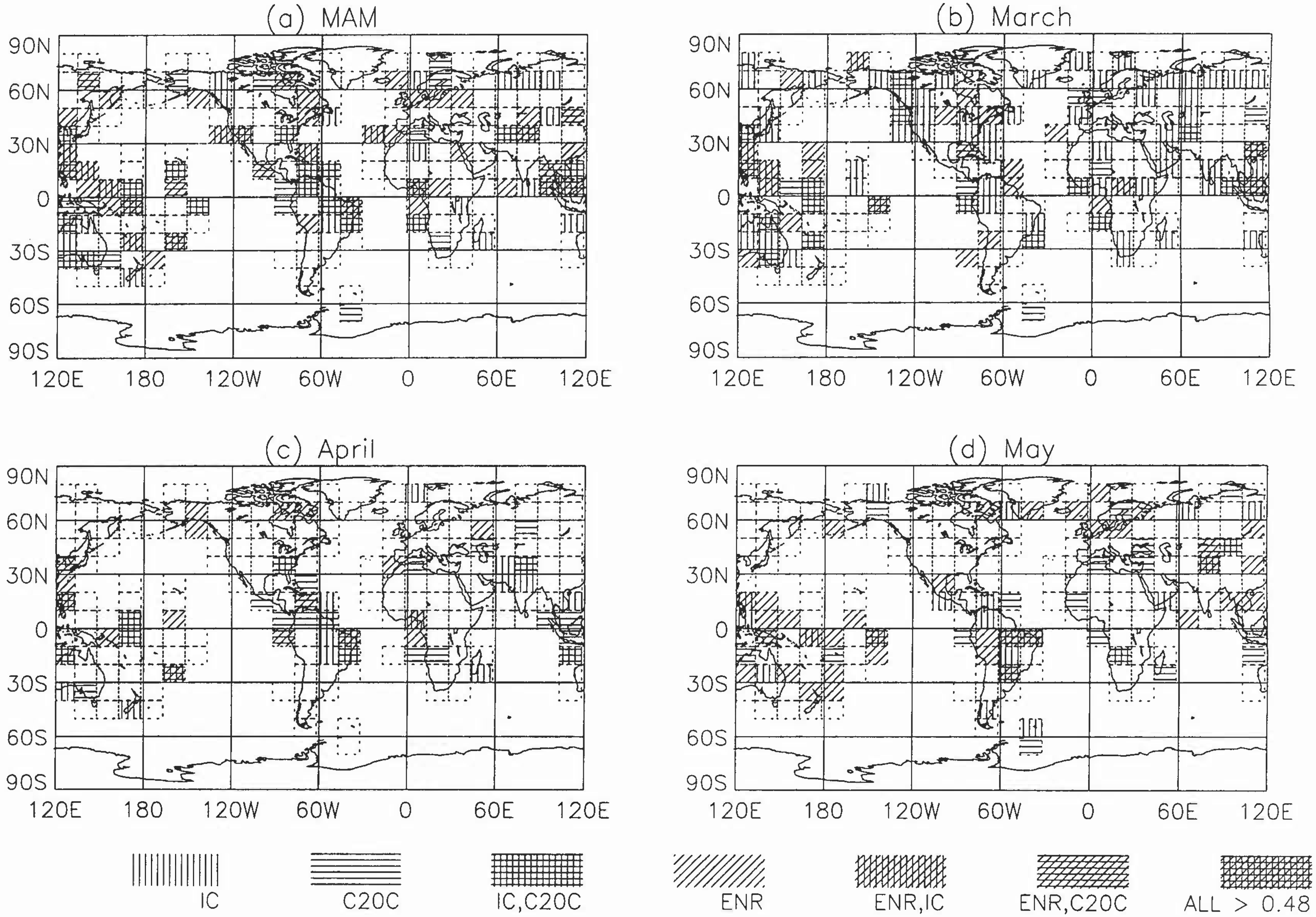

Figure 4: same as figure 3b but IC simulations use November atmosphere initial conditions