OPERATIONAL PREDICTABILITY OF WINTER BLOCKING: AN ECMWF UPDATE

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Abstract

Seven years of analyses and forecasts from the operational archives of the European Centre for Medium Range Weather Forecast (ECMWF) had been previously analyzed to assess the performance of the model in forecasting blocking events (Tibaldi and Molteni, 1990). This work updates some of this previous diagnostic work to the last five winters, from 1987-88 to 1991-92. The data set covers therefore all winter seasons (DJF) from 1980-81 to 1991-92, and consists of Northern Hemisphere 500 hPa geopotential height daily analyses and of the ten corresponding forecasts verifying on the same day, a data set commonly known as the "Lorenz Files". Local blocking and sector blocking have been defined similarly as in Tibaldi and Molteni (1990), using both their original index (itself a modified version of the Lejenas and Økland, 1983 index) and a further modified, and hopefully improved, objective blocking index. The comparison between the first seven and the last five winters suggests a much improved situation as far as model climatology of blocking is concerned, especially over the Euro-Atlantic region. Operational predictability of blocking as an initial value problem is also shown to be measurably improved, in both Atlantic and Pacific sectors. Nevertheless, forecasting blocking remains a difficult task for the model. More work is needed to understand whether the improvements are to be ascribed to the increased model resolution or to better physical parametrizations.

1. INTRODUCTION

Tibaldi and Molteni (1990, hereafter referred to as TM) had previously investigated operational blocking predictability by the ECMWF model and the possible relationships between model systematic error and blocking in the winter season of the Northern Hemisphere, using seven years of ECMWF operational archives of analyses and day 1 to 10 forecasts. They showed that fewer blocking episodes than in the real atmosphere were generally simulated by the model, and that this deficiency increased with increasing forecast time. As a consequence of this, a major contribution to the systematic error in the winter season was shown to derive from the inability of the model to properly forecast blocking.

The inability shown by forecasting models to properly enter into a blocked state (both in the initial value problem sense and in a climatic sense) and the consequential existence of large systematic errors are limiting factors of paramount importance also for extended range forecasts (*Tracton et al*, 1989; *Tracton*, 1990; *Miyakoda and Sirutis*, 1990; *Tibaldi et al*, 1991; *Branković and Ferranti*, 1992), where the consequences of such errors are amplified by the longer integration time. An improved understanding of the reasons for blocking forecast failures and of the positive relationship between such failures and model systematic errors would therefore have an even larger positive impact on extended range dynamical forecasts.

In this study, the analysis performed in TM for the first seven winter seasons of the ECMWF operational model is extended to the subsequent five winters, during which model development, reflecting in both resolution increases and parametrization modifications, continued unabated. The data used are analyses and day 1 to 10 forecasts of 500 hPa

Northern Hemisphere geopotential height fields, December to February, 1980-81 to 1991-92. The organization of the data set and the analysis procedures are described in Section 2, including the description of a new version of the objective blocking index. Section 3 shows and comments the results of the diagnostic work and Section 4 contains a brief summary and some conclusions.

2. DESCRIPTION OF THE DATA SET AND OF THE ANALYSIS PROCEDURES

The database for this study consists of daily Northern Hemisphere winter 500 hPa geopotential heights analyses and the corresponding day 1 to day 10 forecasts. Winter is here defined as the 90-day period spanning the months of December, January and February (DJF period). For each winter day, eleven fields are then available: analysis and day one to day ten forecasts, all verifying on the same day but started from progressively lagging initial conditions. Such an arrangement of analysis and forecast fields is commonly known as a "Lorenz files" dataset (*Lorenz*, 1982). The total set includes twelve complete winters, from DJF 80-81 to DJF 91-92. Since there are eleven fields (one analysis and ten forecasts) relative to each day, the complete dataset consists of 11880 fields. A buffer zone of ten days is added at the end of each 90 day season to allow for blocking events straddling across the season end. The original ECMWF archive data consists of global fields, projected on spherical harmonics coefficients truncated at triangular truncation 40 (T40). For the present analysis the data have been projected on a regular latitude-longitude grid (3.75° x 3.75°) and only the Northern Hemisphere region has been considered.

The forecasting model and the assimilation scheme have constantly been modified during the 12 year period covered by the dataset. Changes have been as major as complete revisions of the physical parametrizations and the changeover from a gridpoint to a spectral numerical scheme. While it had been assumed in TM that the major conclusions concerning the behaviour of the operational model during blocking were likely not to be affected in a substantial way by model and data assimilation system changes deny the first seven years of operations, enough years have elapsed since to make it worthwhile trying to assess whether a measurable positive trend in model ability can be detected. With this idea in mind, and in order to maintain the possibility to compare with the original TM results, the complete 12 years dataset has been arbitrarily divided in two sections, the original TM first seven winters and the subsequent five winters, and comparisons will always be shown here between time-mean quantities averaged over these two periods.

We will also introduce here a modified version of the original TM blocking index (itself a modified *Lejenas and Økland*, 1983 index) which we will refer to as the TMRM index, (*Ruti*, 1992 and *Maruca*, 1990). This new index was developed in order to obtain an improved correspondence between objective and subjective, synoptic evaluation of blocking occurrence, which had been evaluated and found somewhat unsatisfactory with the old TM index (e.g. *Ruti*, 1992). The TMRM blocking index has a more complex structure of the old TM index because it involves both the use of meridional gradient of geopotential height and of height anomaly; the index is adjusted to work best in two particular areas in the northern hemisphere, namely the Euro-Atlantic area (30.00°W-33.75°E) and the Pacific area (165.35°E-146.25°W). The exact definition of the old TM index and the description of the associated blocking criteria are extensively discussed in TM and will not be repeated here.

To identify a blocking situation, the new TMRM index requires that at a given longitude, i.e. at a given grid-point n, the following conditions are satisfied:

a) (GHGS > 0 .AND. GHGN < -10.2 m/deg lat. .AND. ANOM(at 69°N) > 40 m) .OR.ANOM(at 69°N) > 230 gpm (in the Euro-Atlantic sector)

b) (GHGS > 0 .AND. GHGN < -9.5 m/deg lat. .AND. ANOM(at 69°N) > 35 m) .OR.ANOM(at 69°Nn) > 150 gpm (in the Pacific sector) where ANOM indicates an anomaly from a long-term climate of 500 hPa geopotential height and where:

$$GHGS = \frac{Z(\phi_0) - Z(\phi_s)}{(\phi_0 - \phi_s)},$$

$$GHGN = \frac{Z(\phi_N) - Z(\phi_n)}{(\phi_N - \phi_n)},$$

$$\phi_N = 86^\circ N$$

$$\phi_n = 75^\circ N$$

$$\phi_0 = 60^\circ N + \Delta$$

$$\phi_s = 40^\circ N + \Delta$$

$$\Delta = -4^\circ, 0^\circ, +4^\circ \qquad \text{(Euro-Atl.)}$$

$$\Delta = -8^\circ, -4^\circ, 0^\circ, +4^\circ, +8^\circ \qquad \text{(Pacific)}$$

Figure 1 illustrates schematically how the new TMRM index is computed.

The geopotential height (Z) gradient is now calculated between somewhat modified latitudinal limits with respect to those used by TM, to allow a better identification of blocking situations in the northernmost part of the hemisphere. The ".OR.ANOM(at 69°N)>" condition is also introduced to improve the index ability to identify blocking structures when their position is much northern than usual. The ".AND.ANOM(at 69°N)>" condition is used to avoid cataloguing erroneously cut-off lows as blocks.

After a first pass, a second pass is performed, where a given longitude is confirmed to be blocked only if the two adjacent longitudes were also found blocked on the first pass. This defines the local and instantaneous TMRM blocking index. However, a local and instantaneous index such as this is capable, at best, to identify blocking-like structures, but has to be supplemented by further conditions, reflecting the synoptic requirements of spatial extension and time duration which distinguish a transient blocking-like flow pattern from a true blocking event. Such conditions are also used to introduce the concept of sector blocking.

Similarly to TM, the two main NH sectors are then identified and defined, but with the following (modified) longitudinal limits:

Euro-Atlantic:	30.00° W	33.75° E
Pacific:	165.35° E	146.25° W

A sector is then considered to be blocked if three or more adjacent longitudes contained in it are blocked according to the local and instantaneous TMRM index definition. In addition to this criterion based on spatial extension, a further constraint on duration in time is needed to approach the synoptic concept of blocking "a la Rex", if (as we are indeed here) one is dealing with daily 500 hPa geopotential height fields. This has been done (also as it had been done for the old TM index) by requiring, for a blocking event (or episode) to be catalogued, that a sector is found blocked for at least five consecutive days. This is a totally arbitrary limit, which stems from the compromise of having true long-lasting blocking events, but also a sufficient number of them to constitute a minimal statistical base. This further time-duration condition is obviously not used if the index is applied on 5-day mean fields.

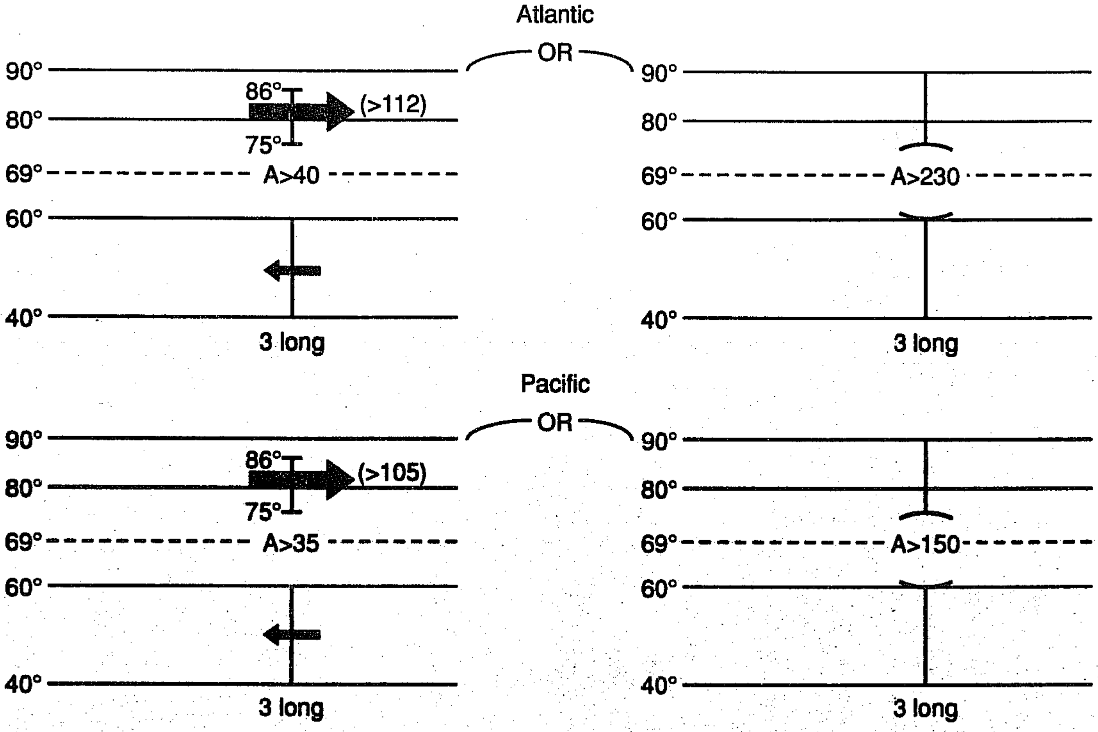

Figure 1 Schematic diagram illustrating the characteristics of the new TMRM blocking index and the differences over the two main blocking areas.

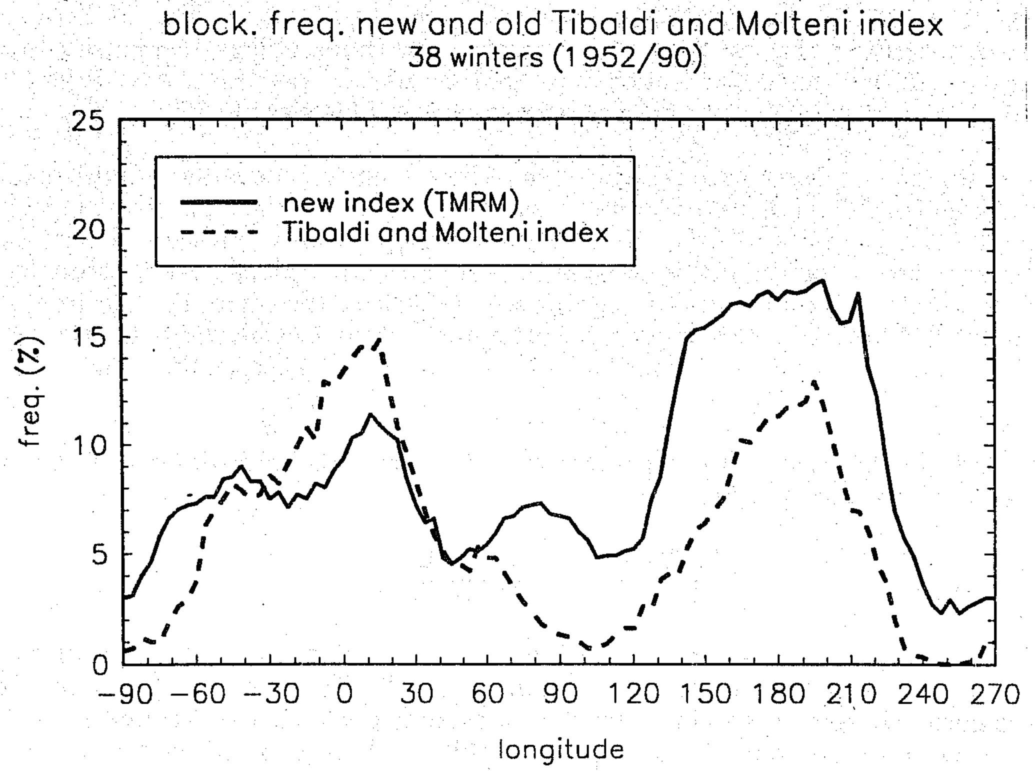

Figure 2 The old TM and the new TMRM blocking indices compared on 38 winters (1952/1990) of 5-day mean (pentads) fields.

An extensive evaluation of the synoptic performance of the new TMRM index can be found in *Ruti* (1992), where both TM and TMRM indices (together with a number of other indices) are synoptically verified against two independent, subjectively produced, NH blocking catalogues. Here we will only show Table 1, where the performance of the new TMRM index is evaluated and compared to the old TM index using as "truth" the subjective synoptic judgement of an expert synoptician (Dr. A. Buzzi). The quantitative measures used to assess the index performance are Bias, Threat Score and Percentage of Success defined as:

Bias = NI/N

Threat Score = NA/(N+NI-NA)

Percentage of Success = ((ZA-ZD)+(BA-BD))/(ZA+ZD+BA+BD)

and

N = total "true" number of blocks (subjectively estimated)
NI = total number of blocks diagnosed by index
NA = number of agreements between index and "truth"
ND = number of disagreements between index and "truth"
ZA = number of zonal agreements
BA = number of blocking agreements
ZD = number of zonal disagreements
BD = number of blocking disagreements

The results contained in the table confirm the superioriry of the TMRM index as far as simulating subjective synoptic judgement.

3. OBSERVED AND PREDICTED BLOCKING

Figure 2 shows the longitudinal dependency of blocking frequency as measured by the two indices applied on a long observational dataset of 38 winters (1952-53 to 89-90) of 500 hPa 5-day means (pentad means) of geopotential height and is shown here only to give a stable measure of the different behaviour of the two indices on a large set of observed data. The main characteristics of the TMRM index compared with the former TM index are a much strengthened perception of Pacific blocking, a slightly weaker, but longitudinally broader, Atlantic blocking and a much more important Asian frequency maximum (around 80°E). These differences will of course also reflect in corresponding differences in the diagnosis of model produced blocks.

The four panels of Figure 3 show blocking frequency relative to the first seven winters of ECMWF operations. Panel (a) shows observations alone, while in panels (b) to (d) forecast day 3, 6 and 10 respectively are superimposed on the observed longitudinal frequency. The disruption of the observed maxima in correspondence of both the Pacific and the Atlantic sectors is quite evident already at day 6 and is almost complete by day 10. This confirms that the results found by TM are not related to the use of a particular blocking index.

Figure 4 has the same layout of Figure 3, but refers to the last five ECMWF operational winters, 87-88 to 91-92. Now the picture is quite different and shows a marked improvement in model climatology of blocking, with the model-produced frequency profile becoming measurably different from observations only by day 10. Figures 5 and 6 show the same graphs in the corresponding panels as Figures 3 and 4, but for the old TM index. The graphs of Figure 5 were also shown in TM, but are reproduced here for ease of comparison.

A further, interesting fact emerging from the analysis of Figures 3-6 is that, irrespectively of the precise index used, the perceived "climatology" (intended as a many-years-time-mean)

	BUZZI	TMRM	TIBALDI	TM-MO
TOT.ZON.	266	283	334	356
TOT.BLO.	418	401	350	328
ThreatScore=		.593	.518	.426
Bias Score=		0.96	0.84	.78
EUR-ATL BLOCKING				
ZONAL	512	520	456	503
BLOCKING	172	164	228	181
ZON.ACC.		475	433	452
BLO.ACC.		127	149	121
ZON.DIS.		37	79	60
BLO.DIS.		45	23	51
ThreatScore=		.608	.594	.522
Bias Score=		0.95	1.33	1.05
percentsucc=		.760	.702	.675
PACIFIC BLOCKING				
ZONAL	438	447	562	537
BLOCKING	246	237	122	147
ZON.ACC.		379	429	393
BLO.ACC.		178	113	102
ZON.DIS.		59	9	45
BLO.DIS.		68	133	144
ThreatScore=		.584	.443	.351
Bias Score=		0.96	0.50	0.60
percentsucc=		.629	.585	.447

Table 1 Objective skillscores of the old TM index and of the new TMRM index computed by comparing them to an independent, subjectively-evaluated (Buzzi) blocking catalogue of 38 winters (1952/90) of 5-day mean (pentads) fields. A second independent subjective synoptic catalogue (Tibaldi) is also compared to the first to provide a "background" measure of index performance.

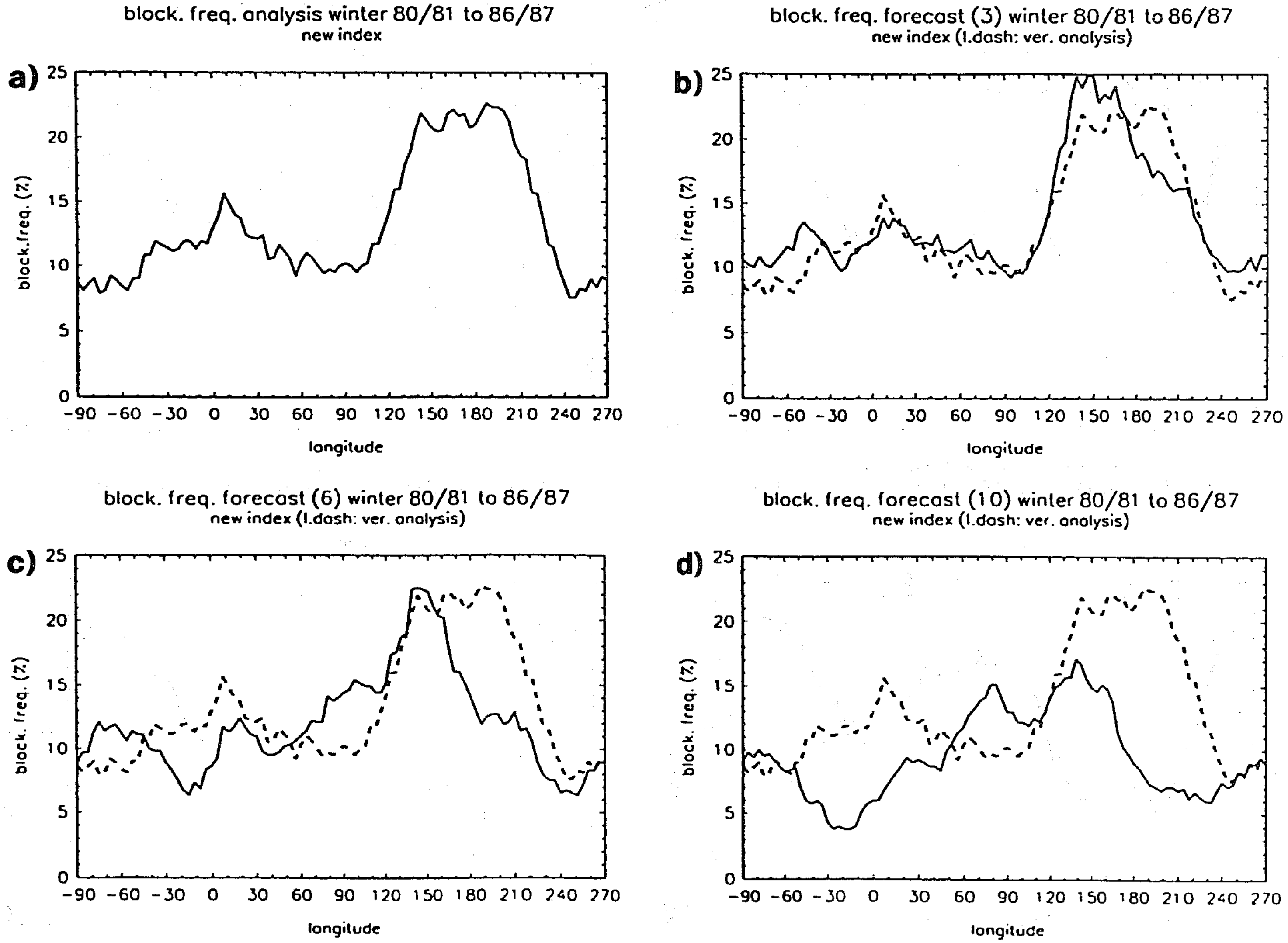

Figure 3 TMRM blocking index applied to the first seven ECMWF operational winters (80/81 to 86/87). (a) analyzed data; (b) forecast day 3 and analysis (dashed); (c) forecast day 6 and analysis (dashed); (d) forecast day 10 and analysis (dashed).

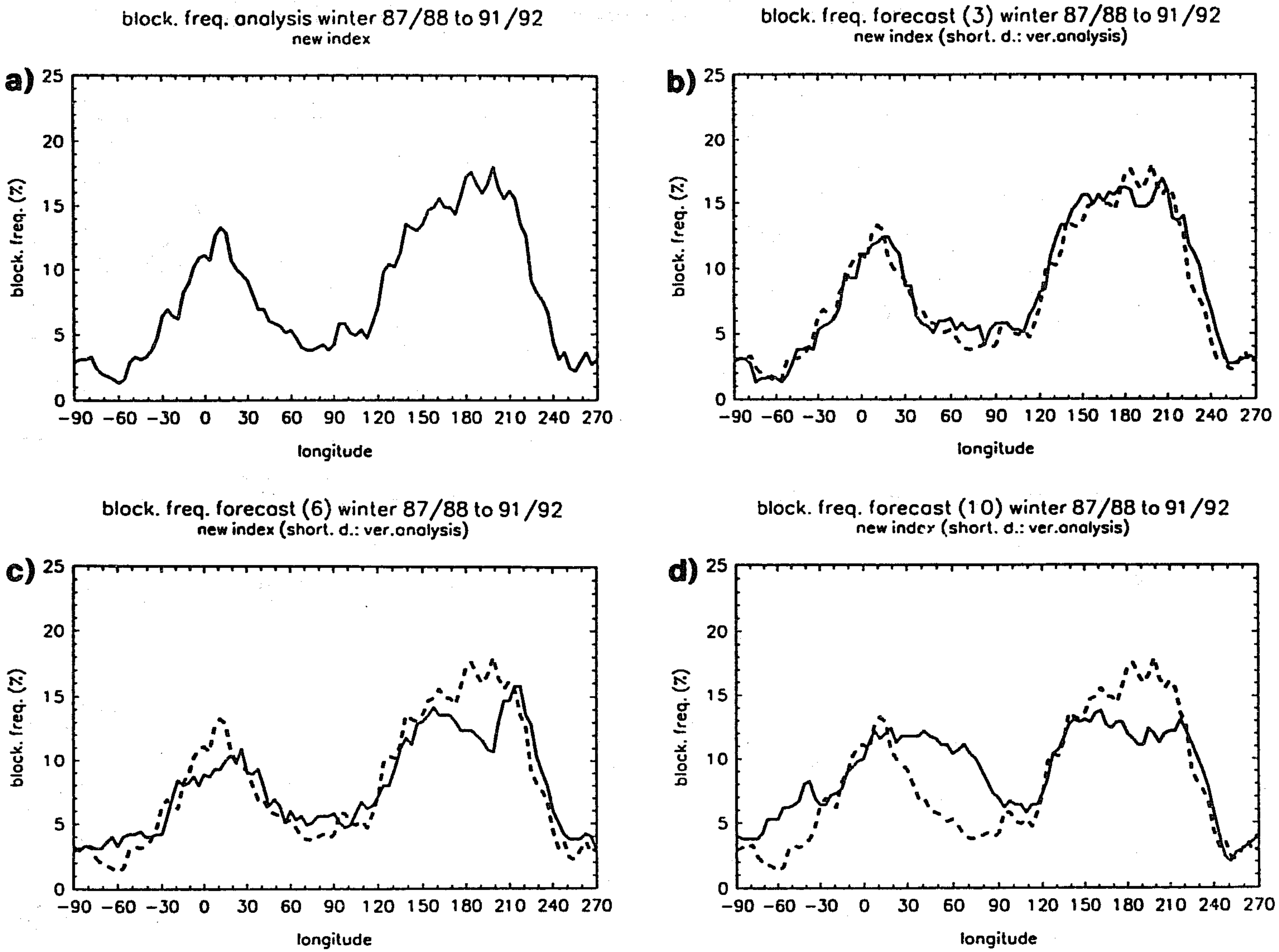

Figure 4 As Figure 3, but for the last five ECMWF operational winters (87/88 to 91/92).

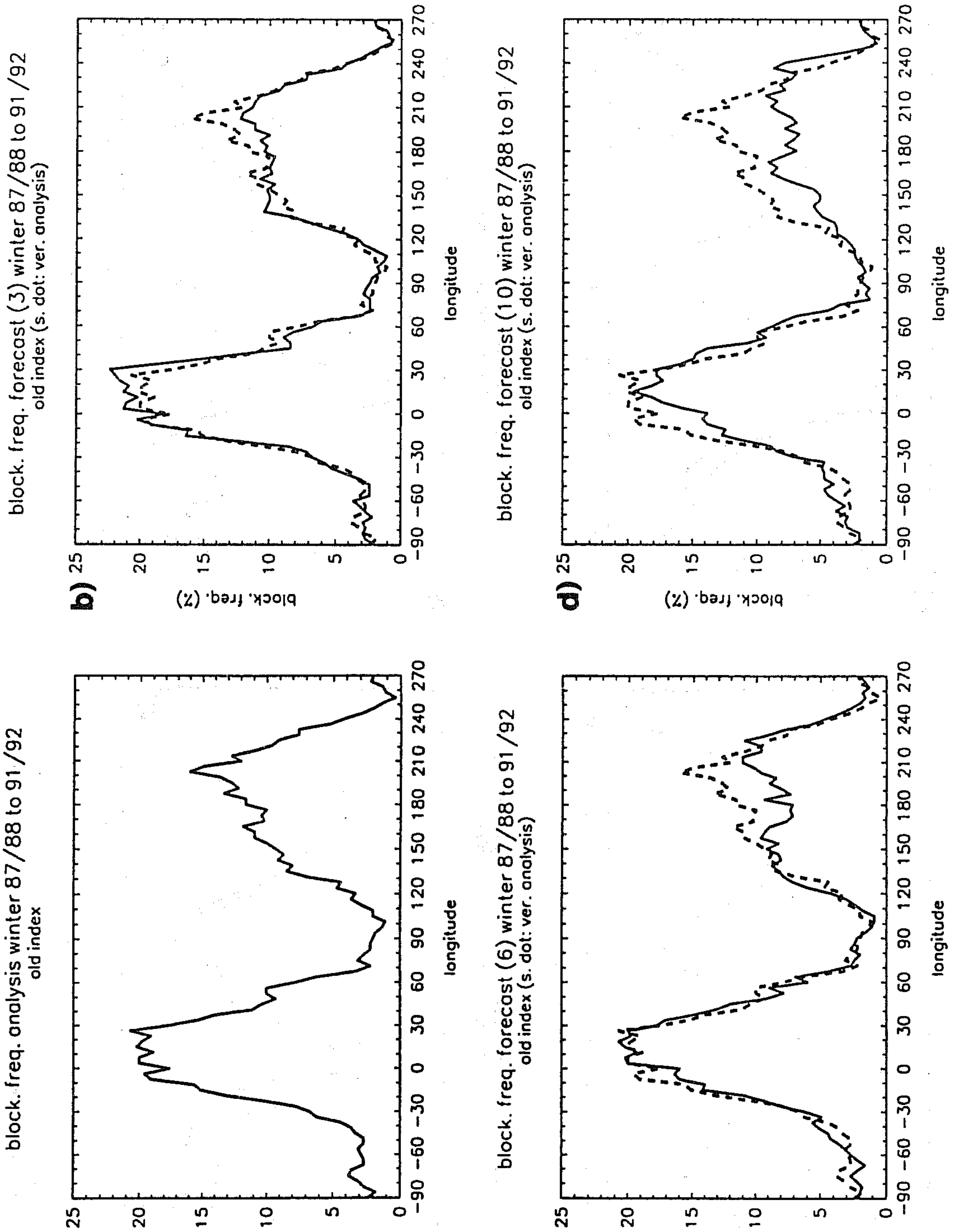

Figure 5 As Figure 3, but for the old TM blocking index.

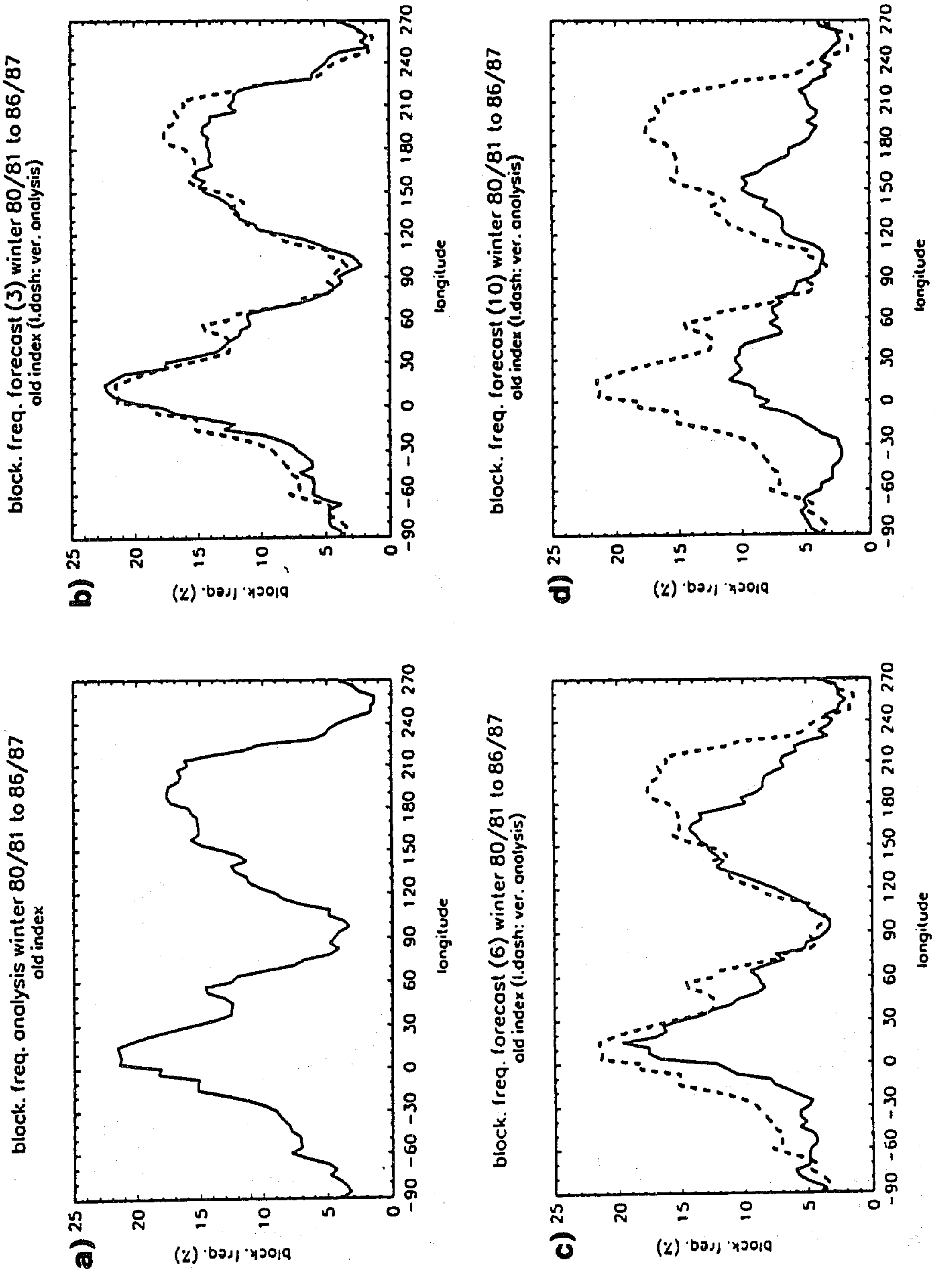

Figure 6 As Figure 4, but for the old TM blocking index.

of the longitudinal distribution of blocking frequency can fluctuate widely. Panels 3a and 4a (the new TMRM index) and 5a and 6a (the old TM index) show indeed very different longitudinal profiles, especially as far as Euro-Atlantic blocking is concerned. This confirms the large inter-decadal variability of observed blocking frequency diagnosed by *Ruti* (1992). This is also clearly displayed in Figure 7, where a time-longitude (Hovmoeller) diagram has been constructed, with the single winter blocking percentage frequency distributions. Areas showing percentage blocking frequency in excess of 15% have been shaded to evidentiate time-space blocking structures, which appear to have a large year-to-year and even longer periods variability.

Having taken notice of the recent improvements in ECMWF model climatology of blocking in the ensemble means at the medium-range, one could still wonder whether such improvements have indeed reflected on the day-to-day deterministic predictability of blocking. Figure 8 attempts to shed light on this problem by comparing how many of the day-n model-blocked days are actually blocked in the verifying analysis as well, separately for the two major blocking sectors. From the figure it is quite evident that, while the total number of model blocks has increased in both sectors, approaching the observed values, the relative proportion of unverified blocks has only decreased appreciably for the Pacific sector (for the Atlantic sector, the relative proportion of shaded bar has remained virtually unchanged from the first seven to the last five years), even if the height of the total bar now decreases much less rapidly with forecast time for both sectors.

Another important conclusion of TM's work was that model blocks were becoming weaker and were drifting in longitude progressively with forecast time. Figures 9 and 10 show the comparison between the first seven and the last five operational years as far as blocking strength (measured by the mean error in the easterly geopotential height gradient) and blocking longitude (measured by the longitude of the maximum blocking strength) are concerned. The progressive weakening of model blocks, as well as the systematic eastward shift of Euro-Atlantic blocks and westward shift of Pacific blocks, have all been drastically reduced to values which, due to the poor sample, are probably statistically indistinguishable from zero.

4. CONCLUSIONS

From the diagnostic work briefly outlined and commented in this contribution it is evident that measurable improvements have been achieved by the ECMWF operational forecasting system in modelling blocking. Such improvements range from a better overall model blocking climatology (reduced climate drift) to an improved deterministic predictability of the phenomenon (mostly limited, however, to Pacific sector blocking). Model blocks are now maintaining the correct amplitude and phase (longitude) practically throughout the entire medium-range. Such improvements make it more realistic to plan for extended range forecasts, where skill variability (and therefore forecast reliability) is often dominated by the model's ability or inability to predict zonal-to-blocking transitions. Unfortunately, the practical set-up of operational forecasting and the related model development efforts make it impossible to ascribe such improvements to a precise cause, be it model resolution (horizontal or vertical) or improvements in the physical parametrization package. More work along the line of case studies is needed to shed light on this problem.

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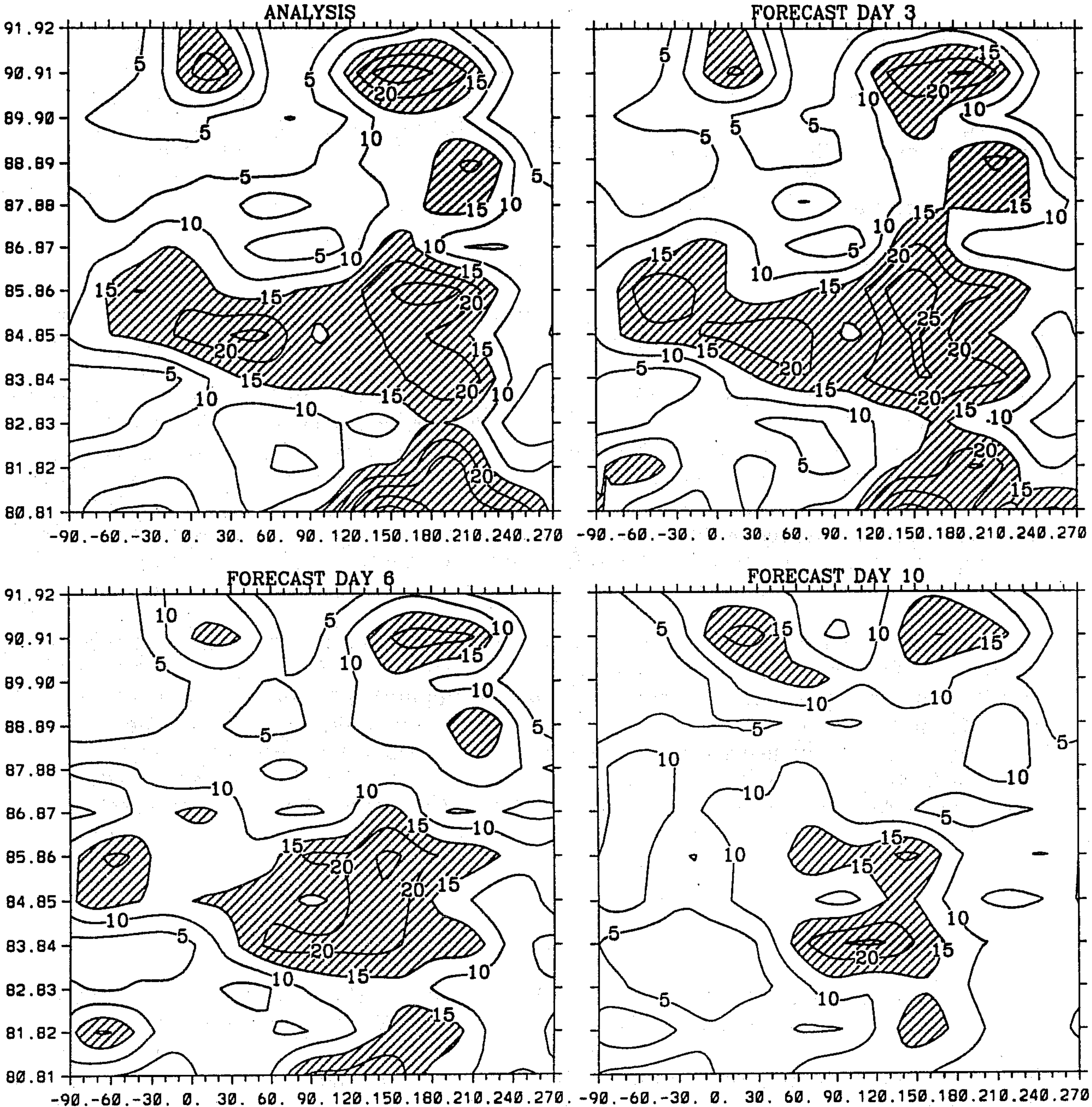

Figure 7 Hovmoeller diagrams of blocking frequency as a function of longitude (abscissa) and time (ordinate).

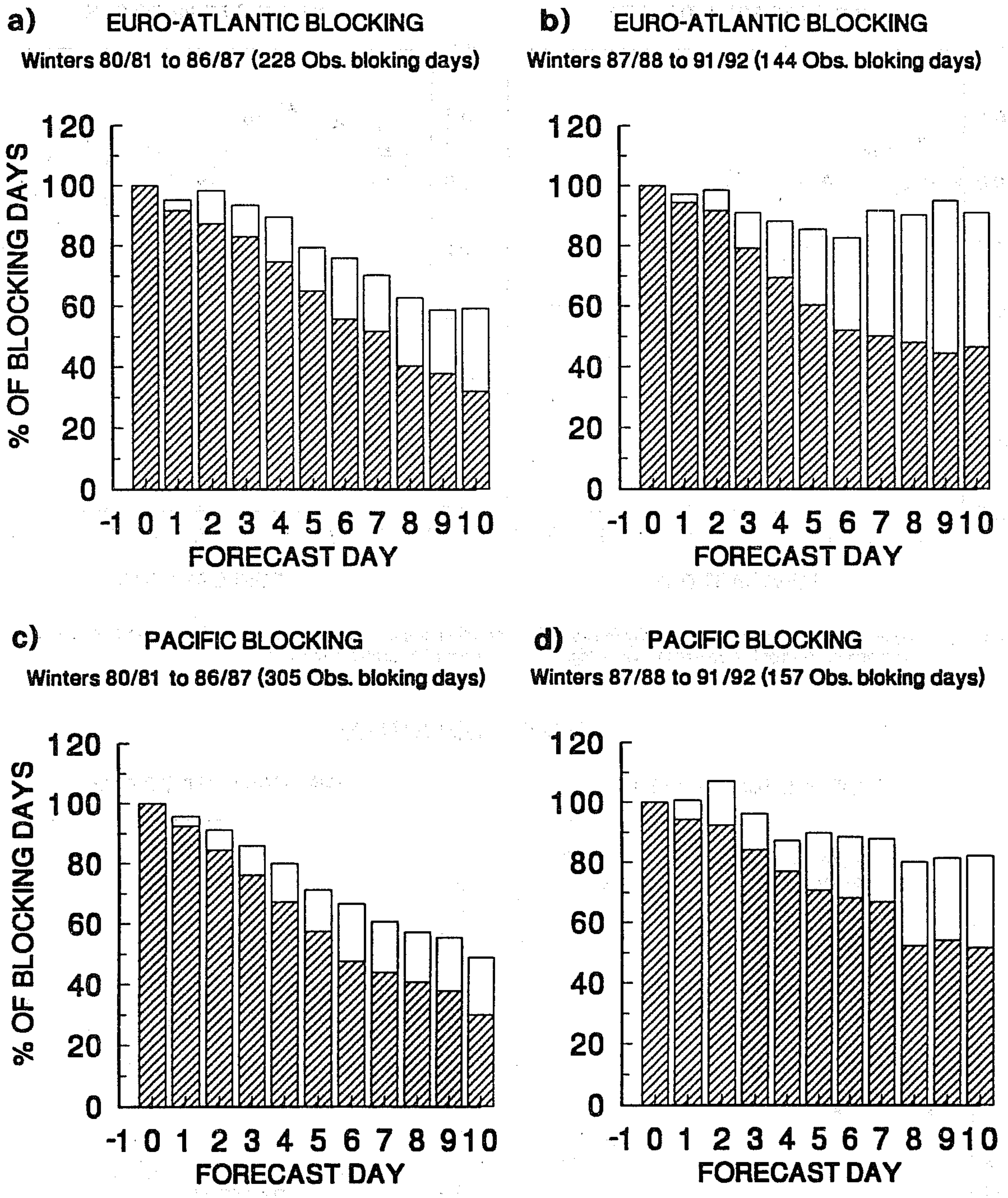

Figure 8 Percentage of blocking days as a function of forecast time in the Euro-Atlantic and Pacific sectors (top and bottom respectively) and for the first seven operational years and for the last 5 operational years (left and right respectively). Hashed bars indicate the proportion of blocking forecasts which verify correctly on that precise day.

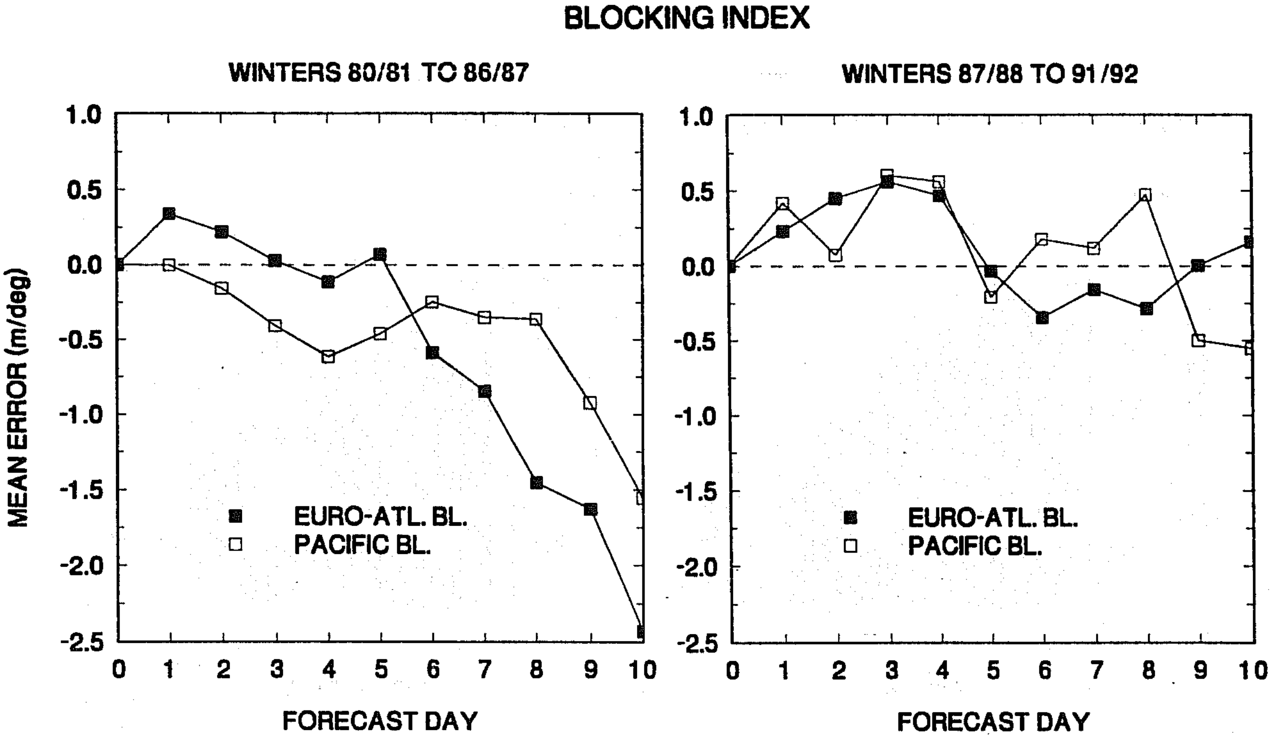

Figure 9 Systematic error on blocking intensity (measured by the value of the blocking index) for the first seven operational years (left) and for the last five operational years (right), for both Euro-Atlantic and Pacific sectors.

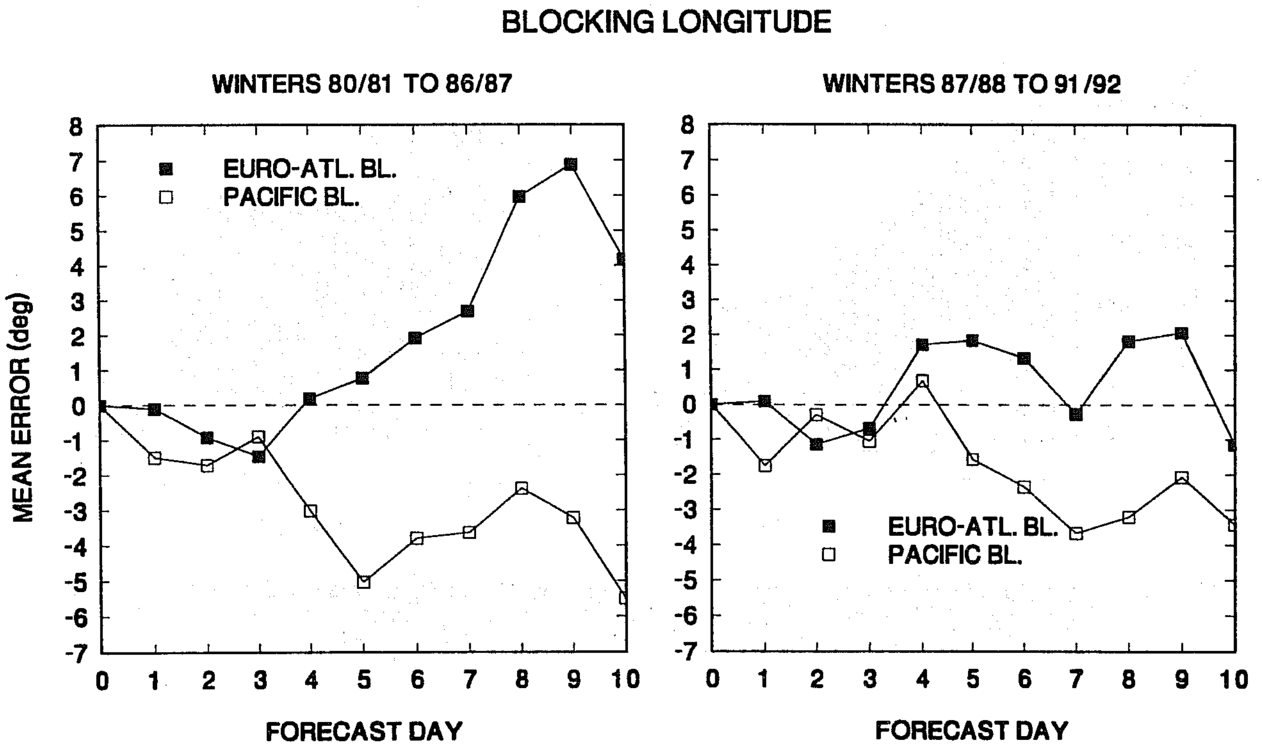

Figure 10 Systematic errors on blocking phase (measured by the value of the longitude at which the maximum intensity occurs) for the first seven operational years (left) and for the last five operational years (right), for both Euro-Atlantic and Pacific sectors.

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