Feature Based Analysis of Reanalyses and AMIP II Integrations

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1. Introduction

The recent reanalysis projects, provide us with our currently, best homogeneous 4 dimensional data sets for the atmosphere over decadal periods. They thus provide a useful resource for studying the global circulation of the atmosphere over a short term climatological period by focusing on both climatologies and variability of a range of space and time scales. The generation of diagnostics from such data can then form the basis of validating climate prediction models. There have been many studies which have used the reanalyses products to generate standard diagnostics, using predominately Eulerian statistical methods. Alternatively a system centered approach focuses directly on the synoptic scale weather systems which are important not only for the day to day weather but cumulatively for local climate. This entails the identification, tracking and derivation of statistical diagnostic fields from the track ensembles. This approach thus provides us with information about the distribution and attributes of the synoptic systems that can often only be inferred from Eulerian methods. This approach has been applied to all the recent reanalyses as well as to the AMIP II integrations. This allows us to intercompare the reanalyses in part to provide some confidence in their use for validating the climate models at the synoptic scale. To perform such studies there have been several automated systems developed in recent years. In this study the automated system developed at Reading (Hodges, 1995, 96, 99) has been used to study the mid-latitude storm tracks in terms of climatologies and variability with respect to the seasons and teleconnections. A wide range of fields and levels have been considered, compared to the traditionally used MSLP. Additionally tropical easterly wave activity has also been studied.

Data from all the recent reanalyses has been use in this study, including ECMWF (ERA15, Gibson et al, 1997) extended with operational analyses to the period 1979-2001, NCEP for the period 1979-1999 (Kalnay et al, 1996), NCEP-DOE for the period 1979-1994 (Ebisuzaki et al, 1998) and GEOS1 for the period 1980-1992 (Schubert et al, 1993) as well as data from the currently available AMIP II integrations for the period 1979-1996 (AMIP II Newsletter). Additionally a limited ERA40 period of two NH winters and summers have been explored as a preliminary analysis for comparison with ERA15.

2. Methodology

In this analysis, systems are identified by their maxima or minima, these are linked together to form system trajectories by the constrained optimization of a cost function. The cost function is based on measures of track smoothness in spherical geometry and the constraints, for displacement and track smoothness, are applied adaptively. The statistical diagnostic fields are also computed directly on the sphere from the track ensembles using spherical kernel estimators with adaptive smoothing, this prevents the introduction of bias. Before the statistics are computed the track ensembles are filtered to remove all systems that last less than 2 days and which travel less than 1000Km so that we are considering only the most coherently propagating systems. The currently available statistics are feature, track, genesis and lysis densities and mean attributes for intensity, speed/velocity, lifetime, tendency and growth/decay rates. All density statistics are scaled from pdf's to number densities per month.

Both the extra-tropics and tropics are explored for storm track and EW activity respectively. The first stage of the analysis has been to compare the various re-analyses. For the storm track comparison a wide range of fields are analyzed, facilitated by the much wider range of fields and levels that are available from the re-analysis projects. This gives a broader view of the storm tracks than the traditional approach of tracking systems in the surface fields only. The range of fields explored are shown in Figure 1 ordered according to the relative spatial scales, in a geostrophic sense, of features that can be identified in them.

$$\left.\begin{array}{c} MSLP \\ Z_{850}\ , Z_{250} \end{array}\right\} \rightarrow \left.\begin{array}{c} V_{850}\ , V_{250} \\ T_{850}\ , T_{250} \\ \theta_{PV\ =2} \\ \Omega_{500} \end{array}\right\} \rightarrow \begin{array}{c} \varsigma_{850}\ , \varsigma_{250} \\ PV_{\theta=330\ K} \end{array}$$

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Large Scale Small Scale

Figure 1: Fields available for the ECMWF reanalysis. Not all these fields are available for the other reanalyses or for the AMIP II integrations.

However, for some of these fields it is difficult to identify the synoptic scale features due to the strong meridional gradients, additionally some fields are more strongly influenced by the planetary scale (large scale, low frequency) background, e.g. MSLP. To be able to identify the features we are interested in, all the fields are filtered to remove the instantaneous large scale background represented by the spherical harmonics of total wave number n <=5. This results in positive and negative anomalies, both of which are identified. A sensitivity study has shown that the features in some fields are more sensitive to this filtering process than others. For example, MSLP is the most sensitive to the number of wave numbers removed, removing too many wave numbers can affect the systems detrimentally, whilst the relative vorticity is the least sensitive. The chosen cutoff is a compromise between these two extremes. In addition since we are only interested in the synoptic scales and some fields are very noisy at the high integration resolutions of the re-analyses (T106 for ERA and T213 for the ECMWF operational analysis, T63 for NCEP) the fields are spectrally truncated to T42 at the same time as the filtering. Finally, to suppress any high frequency noise resulting from the truncation a tapering filter (Sardeshmukh and Hoskins, 1984) is applied to the spectral coefficients. Most of the AMIP models are integrated at similar (T42) resolutions, the same process is applied to these also, except where the model integration is significantly lower a spectral truncation appropriate to the lower resolution is used. For both the re-analyses and AMIP the northern and southern hemispheres are explored for each season (DJF, MAM, JJA, SON) for both signs of anomaly to produce climatological statistics, this together with the wide range of fields and statistics that are available results in a large number of diagnostics. For general storm track statistics the 850hPa relative vorticity is preferred in the lower troposphere to the traditional MSLP field. The reason for this is that it is less influenced by the planetary scale background, it allows a focus on smaller spatial scales such as typified by Mediterranean storms and it is does not depend on extrapolation like the MSLP field. In the upper troposphere the potential temperature on a PV=2 surface is preferred as a measure of activity on a dynamical tropopause. Unfortunately this is a field which is not commonly archived.

The storm tracks are also explored, mainly for the NH winter, for their response to various teleconnections, namely North Atlantic Oscillation (NAO), Arctic Oscillation (AO), Pacific North American Pattern (PNA) and El Nino Southern Oscillation (ENSO). This is done by taking the monthly normalized and centered teleconnection indecies either computed from the MSLP for each model (NAO, AO) or as observed (ENSO) and using them as additional weighting in the statistical estimation. The weights are computed based on one sided hyperbolic tangent functions of the index so that weak values (<1 STD) are progressively down weighted. This is a more systematic and objective way of computing the teleconnection statistics than arbitrarily deciding which months are strong enough to contribute to the positive or negative phase of the teleconnection statistics.

For the tropical EW activity the relative vorticity field is the most appropriate field to use. Because these systems can have a complex 3 dimensional structure, for example over Africa, we use three levels from the re-analyses, 850, 700 and 600mb. However, for AMIP only the 850mb level is available. As with the storm track analysis the high resolution vorticity fields are truncated to T42. Vorticity is probably the noisiest field and the truncation acts to smooth out the noise. No further filtering or smoothing is applied since the EW are often very weak. The period of May-October is explored for the NH.

3. Intercomparison of Reanalyses

The overall impression from the whole range of statistics generated from the various reanalyses if that qualitatively they are very similar in terms of the distribution of synoptic systems and their characteristics. This is particularly the case in the lower troposphere where the majority of observations are available but less so in the upper troposphere and tropics where observations are more limited. This can be understood in terms of the different means of assimilating the observations in the various reanalysis.

In the lower troposphere The ECMWF, NCEP and NCEP-DOE reanalyses show a particularly good agreement in the mid-latitude regions across all the fields and statistics. In particular the track density and mean intensity distributions for the positive anomalies in the 850hPa vorticity field, Figure 2, shows both oceanic storm tracks with near identical distributions in these reanalyses, this extends to the Siberian and Mediterranean storm tracks. This is encouraging since these three reanalyses are based on models with different physical parameterizations, are integrated at different resolutions and use differing means of data assimilation, Optimal Interpolation (OI) for ERA15, 3D/4D Var for the operational analyses and 3D Var. for NCEP/NCEP-DOE. The main differences appear to be that the mean intensity of systems in the two main storm tracks and the track density at high latitudes appear to be slightly greater for the ECMWF data than for the other reanalyses. This can be understood in terms of the integration resolution of these reanalyses, T63 for NCEP, NCEP-DOE; T106 for ERA15 and T213 for the operational analyses. The results for the GEOS1 reanalysis, whilst qualitatively similar show more differences in the detail, in particular a slightly more active Pacific storm track and some differences in the Icelandic region. The GEOS1 system is probably the most different from the other systems in that it is based on a finite difference model (the others are all spectral), has different physical parameterizations, and its data assimilation system uses a more sophisticated form of OI based on a form of nudging (Incremental Update). These aspects can be explored in more detail by focusing on individual regions, for example the European sector.

The upper troposphere shows the greatest differences between the various reanalyses. For the small scale fields, ξ_{250}, PV_{330}, the ERA15 results show a much reduced level of activity, in particular in the western Pacific, this is in contrast to the ECMWF operational analysis and the NCEP/NCEP-DOE and GEOS1 reanalyses. The reason for this disparity for ERA15 appears to be due to the propensity for individual systems to often form multiple centres and for some systems to make large un-realistic jumps in displacement and/or direction (a similar situation occurs in the tropics for easterly wave activity in data sparse regions), thus resulting in fragmented tracks which are removed by the track filtering. Whilst this could be fixed to some degree by improvements to the tracking algorithm, this result highlights the limitations of basic OI with respect to the representation of propagating systems in data sparse regions, the more sophisticated assimilation systems appear able to use the available observations in a much better way.

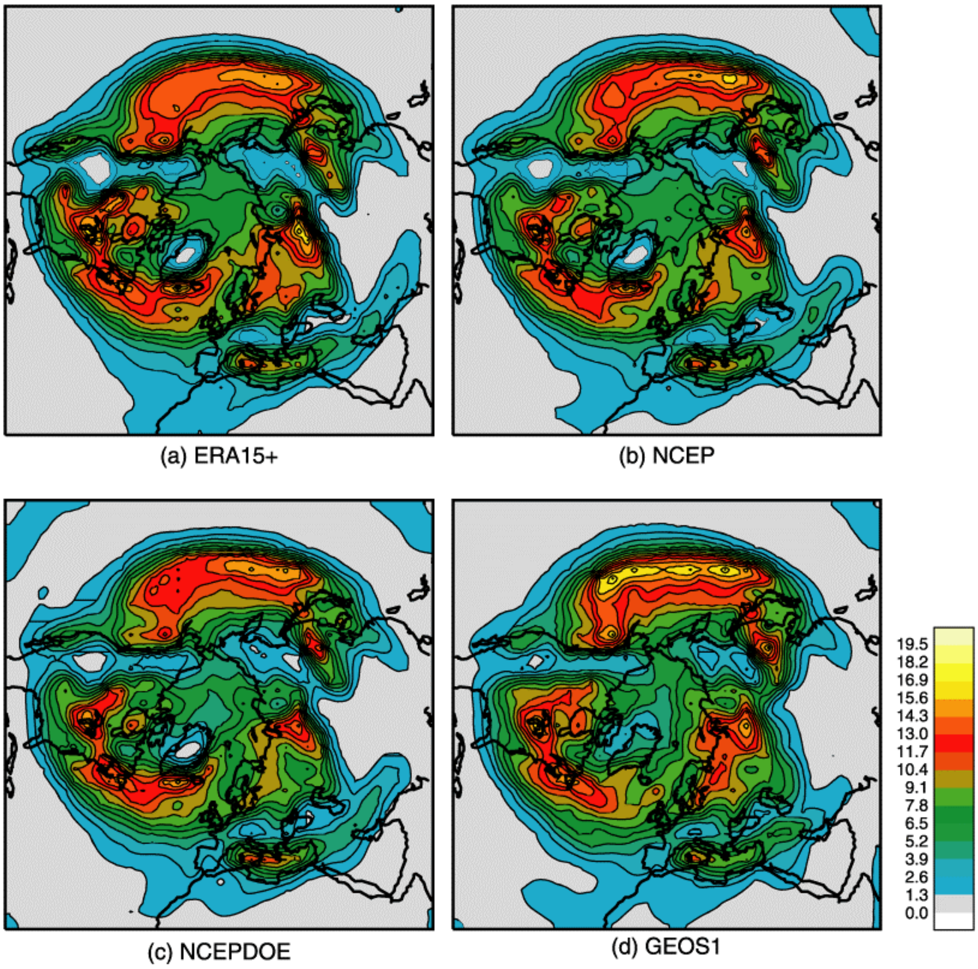

Figure 2: NH winter track density (number density per month) for ξ_{850} for the four reanalyses (a) ERA15+, (b) NCEP, (c) NCEP-DOE and (d) GEOS1.

This is highlighted further by a preliminary analyses of ξ_{250} from ERA40 which uses the 3D Var. system. This shows some improvement over the ERA15 data and is comparable with the NCEP data for the same period (this is further emphasized by the easterly wave activity which shows a similar improvement, although the increased resolution of ERA40 is also important for these weak systems). However, since its introduction the 4D Var. system used currently operationally by ECMWF shows further significant improvements in the representation of propagating systems in data sparse regions and should be considered for future reanalysis projects if feature based analyses are required.

4. Comparison with AMIP II Models.

The AMIP II integrations cover a range of resolutions from very coarse (~5^0) to finer resolutions (~2^0) and use a range of numerics and physical parameterisations. Comparing the reanalyses with the AMIP II integrations provides an interesting test of the fidelity of the AMIP models in reproducing the characteristics of synoptic systems in terms of their distribution and mean attributes and is useful in highlighting systematic problems with the models. To perform this comparison the ξ_{850} is the primary field used for the storm tracks and EW activity. Other fields are also considered but fewer are archived compared to the reanalyses.

For the AMIP models the storm track behaviour appears to vary considerably, with some models having relatively weak storm track activity and others stronger storm track activity. The low resolution models invariably have a weak storm track activity. This is shown in the track density statistic for the NH shown in Figure 3. Most of the models as well as getting the activity level wrong are also too zonal in orientation with in particular too much activity into northern Europe. The representation of the orography in the models is also an important factor particularly for the generation of systems in the lee of the Rockies for example. The reasons for these systematic errors will necessarily require a more detailed analysis of such factors as the parameterizations used for each model.

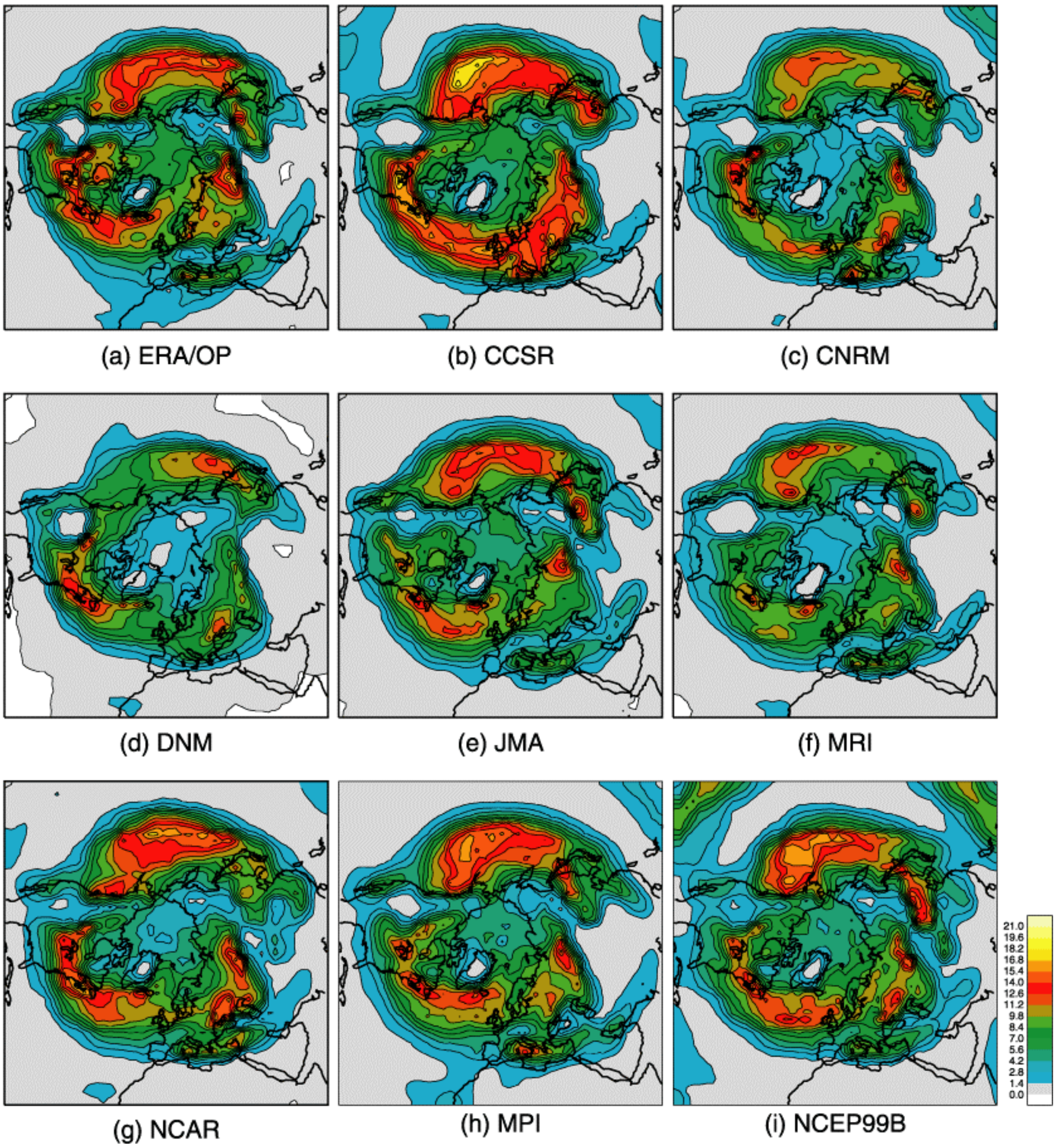

Figure 3: AMIP II track densities (number density per month) for the NH winter (DJF) for ξ_{850}.

For the EW activity the AMIP models have wildly varying degrees of activity, considerably more so than was the case for the storm track activity. This is probably due to the nature of these systems which are often very weak compared to extratropical systems and are not well resolved by coarse resolution models . Of particular interest is the NCEP model on which the NCEP-DOE re-analysis are based. This appears to be very active throughout the tropics and may explain why the NCEP-DOE reanalysis looks very different from the ECMWF and first NCEP reanalysis.

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