

Stochastic input to convection based on subgrid humidity distributions

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ABSTRACT

Due to its binary “on/off” nature, convection can have a large sensitivity to small perturbations. Thus the convective process is an obvious candidate for parametrization in a stochastic framework, to attempt to include its potential significant impact on forecast uncertainty. Part of this uncertainty has previously been associated with the lack of knowledge or neglect of variability in humidity on spatial scales not resolved by forecast models. This work shows preliminary results where a simple methodology is employed to take this into account. The ECMWF integrated forecast system does not explicitly model the evolution of the subgrid-scale humidity distribution, but many model components make implicit assumptions concerning this aspect. For compatibility with the forecast model’s nonlinear cloud scheme, a uniform distribution of total water variability is diagnosed. Each member of the ensemble prediction system then uses this distribution to estimate the uncertainty of convection in two ways. Firstly, the boundary layer parcel which is used to test for convective instability randomly samples the boundary humidity distribution, in other words, the convective event can originate from the driest or the wettest location within the grid-box, rather than always having grid-mean properties. Secondly, the variability of the humidity of the environmental air entrained into the convective updraughts is also taken into account. Preliminary results show that the humidity variability has an impact on ensemble spread comparable to but less than the default stochastic physics scheme. Moreover, the new scheme provides additional spread in the tropics, an area where the current scheme has little impact, with the midlatitudes then being influenced in the medium range. Longer experiments also show a shift in the tropical climate, with less convective rainfall and smoother total precipitation fields over the oceans. Further work will be required before the scheme can be operationally implemented as a supplement to the existing stochastic physics scheme, but indications from this pilot investigation are promising.

1 Motivation

Uncertainty of forecasts is often categorized as resulting from uncertainty in the initial conditions, and inaccuracy of the forecast model (Palmer, 2000; Orrell, 2005). An attempt to address the former can be made by the use of singular vectors, which attempt to find the analysis perturbations to which the subsequent forecast is most sensitive, for a given set of metrics over a specified target region for a certain forecast range (Molteni et al., 1996; Palmer et al., 1998). The model error can be approached by adding suitable stochastic perturbations to the model physics parametrization scheme output thermodynamic and/or dynamic tendencies, in order to account for their presumed inaccuracy (Buizza et al., 1999).

One parametrization of a physical process which often receives attention with regard to stochastic physics schemes is deep convection. Small but finite changes to boundary layer or free-tropospheric thermodynamic properties which alter the convective inhibition (CIN) can determine whether or not deep convection occurs. Thus deep convection appears to be an efficient vehicle for the rapid amplification of small-scale and magnitude perturbations if the net convective effect can influence synoptic-scale circulations efficiently. This is why convection is regarded as a suitable candidate for parametrization by a stochastic approach.

The study of Zhang et al. (2003) examines the predictability of the January 2000 rapidly intensifying storm that affected the East coast of America. They showed that the failure to predict this system stemmed from the influence of the embedded deep convection. Small scale uncertainties, which they attributed to the lack

of knowledge of temperature and humidity fluctuations on scales smaller than the mesoscale model grid, influence the location and occurrence of deep convection and lead to variations in the predicted system path and its ultimate magnitude. [Buizza and Chessa \(2002\)](#) confirmed that the use of stochastic physics to provide parametrization (including convection) tendency perturbations enabled some of the ensemble prediction system (EPS) members of the ECMWF forecast model to provide improved predictions of this storm. More generally, [Lin and Neelin \(2000, 2002, 2003\)](#) have introduced convective stochastic physics parametrizations into a model and have shown a significant impact. It appears justifiable therefore to consider convection an important contributor to forecast uncertainty, which warrants parametrization in a stochastic framework. This article will outline a simple but novel approach to a stochastic convective parametrization¹.

One potential criticism of stochastic physics schemes in general, and convective schemes in particular, may be their ad hoc nature of implementing the perturbations. The scheme introduced by [Buizza et al. \(1999\)](#) multiplies parametrization output tendencies by a constant factor. Likewise, ([Lin and Neelin, 2002](#)) multiplies convective closure parameter of convective available potential energy (CAPE) by a constant factor. The argument is that the level of uncertainty is likely to be larger when the scheme itself is producing a large effect. It is clear that this is not always the case. For the case of convection, a grid cell might be very close to a critical unstable state that could sustain deep convection. The convection scheme does not initiate convection and the parametrization produces zero tendencies. The assessment of “uncertainty” by the stochastic physics is thus also zero despite the fact that a small positive perturbation to the boundary layer temperature may be enough to instigate significant deep convection. This highlights the possible shortcomings of not taking the potentially best knowledge of “parametrization (output) uncertainty” into account. [Shutts \(2004\)](#) recently outlined a stochastic backscatter scheme that attempts to implement the stochastic perturbations in the regions where the energy dissipation rate is largest.

What are, in fact, the causes of parametrization uncertainty? One oft-quoted cause is due to deficiencies in the formulation of the parametrization itself: simplified, missing or simply misrepresented physics; bluntly speaking parametrization ‘mistakes’. However, another, less focused upon, was highlighted in the study of [Zhang et al. \(2003\)](#). They point out that uncertainties in convective heating would arise due to the lack of knowledge of subgrid (small) scale fluctuations of temperature and humidity. Imagine two grid-columns with identical thermodynamic profiles. The first has no subgrid variability, and all subgrid ‘parcels’ are unable to initiate deep convection. The second column instead has much subgrid variability, and thus some of the most energetic subgrid parcels may spawn convection. Thus forecast uncertainty would arise even with a ‘perfect model’ simply due to the neglect of variability below the truncation scale of the model.

The work outlined here aims to introduce a simple approach to including the best estimate of subgrid-variability into a convective stochastic physics scheme. In this way, the convective uncertainty is related to the local thermodynamic and dynamic conditions.

2 Implementation

2.1 convection scheme

The convection scheme used in the ECMWF model is a so-called mass flux scheme described by [Tiedtke \(1989\)](#) and [Gregory et al. \(2000\)](#). It bases its estimate of convective mass fluxes and associated heating, moisture and momentum transport on input column profiles of temperature and humidity. A theoretical ‘parcel’ of air consisting of the mixed layer mean temperature and humidity properties is lifted vertically to test for conditional instability in the column. If positive CAPE is found, and any CIN present is insufficient to de-accelerate the parcel to a zero vertical velocity (essentially constituting the scheme’s convective ‘trigger’), then the scheme will produce deep convective heating rates proportional to the CAPE. In addition to the parcel properties,

¹It should be emphasized that this is not to claim that convection is the only, or indeed the most important process to be treated stochastically.

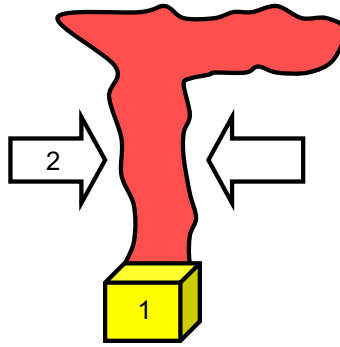


Figure 1: Schematic of the ways in which model humidity affects deep convection. (1) the box represents the PBL properties which are sampled to give the initial properties of a convective 'test' parcel, which is raised to its level of neutral buoyancy to test for deep convective potential. (2) During this ascent the parcel is subject to entrainment, and thus humidity during the ascent will also affect convective potential and strength. . See text for details.

during the parcel ascent environmental air is entrained at a fixed rate and thus in this way the humidity profile throughout the grid column also affects the ultimate convective heating.

From the description of the scheme it is apparent that increasing the boundary layer humidity (and/or temperature, although the discussion will focus on humidity for reasons given below), and thereby the parcel original equivalent potential temperature, will make deep convection more likely to occur and stronger when it does by its increase in CAPE (see '1' in schematic of fig. 1). Likewise the entrainment of dry or cold air reduces the buoyancy of convective plumes and is likely to suppress convection (e.g. Nicholls and Lemone, 1980; Parsons et al., 2000; Tompkins, 2001; Redelsperger et al., 2002; Chaboureau et al., 2004; Derbyshire et al., 2004), point 2 of fig. 1. The role of the perturbations to the parcel's properties (deriving from the boundary layer) and the free troposphere on CAPE and CIN is discussed at length by Parker (2002), who points out that the CAPE behaves fairly linearly in response to such perturbations, but the behaviour of CIN (and hence convective triggering) is more subtle, depending critically on the depth of the CIN layer in addition to the magnitude of the negative buoyancy perturbation. Of direct relevance to this work is the study of Lopez and Moreau (2005), who analysis the Jacobians of the operational convective scheme, that is, the sensitivity of the scheme's output tendencies to perturbations in input humidity and temperature (see their figures 10 and 11). They demonstrate that humidity perturbations have by far the greatest impact in the boundary layer, through their influence on the test parcel's properties. There is also a secondary peak of sensitivities in response to humidity perturbations in the lower troposphere, where entrainment affects shallow and deep convection significantly.

Lopez and Moreau (2005) also highlight that PBL humidity perturbations have greater effect than temperature as expected, since humidity fluctuations in the boundary explain most of the variability in equivalent potential energy. Moreover, above the boundary layer, virtual temperature fluctuations are likely to be smaller as they are efficiently removed by gravity waves, and have been documented as secondary in data analysis by Price (2001) and Tompkins (2003). Therefore, based on their secondary importance, and to simplify the initial implementation, only humidity fluctuations are considered in this work. In agreement with this emphasis, both Kingsmill and Houze Jr. (1999) and Sherwood (1999) have highlighted the importance of PBL and lower tropospheric humidity as a convective activity precursor.

2.2 subgrid variability

If the subgrid variability of the humidity and temperatures is to be taken into account by the convective ascent, the first issue that needs to be tackled is the source of the information concerning this subgrid-scale variability within each grid-cell. In fact many GCM schemes already contain implicit assumptions concerning subgrid variability, such as the cloud water adjustment made in radiation schemes (e.g. Cahalan et al., 1994), or estimates used in the evaporation of rainfall (e.g. Jakob and Klein, 2000).

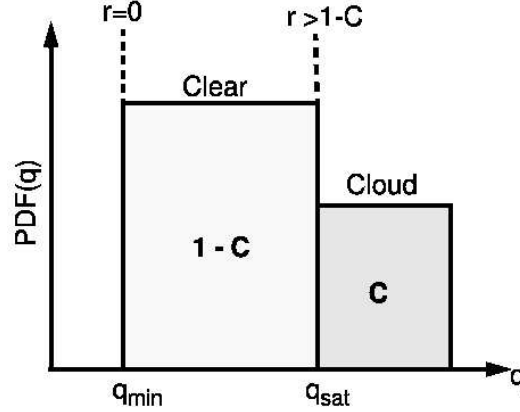


Figure 2: Schematic of the assumed subgrid-scale distribution of humidity and cloud water. See text for details and definitions.

A more desirable source of subgrid information would be an explicit parametrization, such as those implemented in statistical cloud schemes (e.g. Smith, 1990; Golaz et al., 2002; Tompkins, 2002). These make explicit diagnostic, as in the case of Smith (1990), or prognostic (Tompkins, 2002) assumptions concerning the evolution of a low-order probability density function (PDF) describing the fluctuations of temperature and/or total water (humidity+cloud water). While the cloud scheme employed in the ECMWF IFS does not explicitly employ a statistical scheme framework, many of the central parametrization assumptions are built around the central assumption of a uniform distribution for the humidity distribution in the clear sky portion of the grid cell (Jakob, 2000). This is illustrated schematically in fig. 2². This information will be used to provide consistent perturbations of humidity variability for the convection scheme. The clear sky distribution is simply determined. If cloudy conditions exist, and the grid mean relative humidity exceeds 80%, then the clear sky distribution maximum is equal to the saturation mixing ratio q_{sat} . Therefore, the distribution minimum is given by

$$q_{min} = \frac{2\bar{q} - (1+C)q_{sat}}{1-C}, \quad (1)$$

where C is the cloud fraction and the overline represents the grid-mean humidity mixing ratio. In the case of clear sky conditions, when the relative humidity is less than 80%, then no further information is available to determine the variance or higher order moments of the humidity distribution. This lack of variability memory is the disadvantage of a cloud scheme where the prognostic quantities are integrated statistics such as cloud cover or cloud water mass mixing ratio (Tompkins, 2002). In this case one has to resort to a fixed diagnostic assumption concerning humidity distributions, and the distribution width is fixed to 40% relative humidity, giving

$$q_{min} = \frac{\bar{q} - Cq_{sat}}{1-C} - 0.2q_{sat} \quad (2)$$

The humidity distribution is sampled by taking a single random number $r \in [0, 1]$ for each grid column which is uniformly distributed to be compatible with the assumed underlying distribution for humidity³. This latter

²Here we have illustrated the assumed distribution in the cloudy region to be uniform, while in fact many of the processes of the Tiedtke (1993) cloud scheme assume no sub-cloud fluctuations of cloud water exist, implying a delta function is more appropriate.

³As an aside, we note that the standard convection scheme does not, in fact, take the grid-mean values of temperature and humidity to initialise the test convective parcel, but actually adds a small excess of 0.2 K and 0.1 gkg^{-1} , respectively, in addition to a positive upwards velocity. These excesses, which are temporally and spatially invariant, crudely account for some estimate of subgrid-scale variability, and implicitly assume that temperature, humidity and velocity perturbations are always positively correlated in the test parcel. In other words the test parcel is the most energetic. Here, by randomly sampling the humidity distribution, but retaining the fixed temperature and velocity excesses, this assumption is broken, and instead *no* correlation between temperature and humidity is assumed. In the case of orographically forced convection this could be an improved hypothesis, while for parcels originating in a

point is crucial, since the temptation is to abandon the uniform distribution in favour of a likely more realistic distribution such as the Gaussian, or even skewed PDF such as the Beta distribution. This is not done for reasons given by Tompkins (2002), namely that it is undesirable to introduce further separate assumptions concerning subgrid-scale variability into each model component, therefore interminably increasing the number of “tuning” parameters in the model. The aim should be to introduce one central key PDF for subgrid variability, and to use this consistently in all model parametrization components, such as convection, clouds, radiation, and in this case stochastic physics.

If the random number falls into the clear sky part of the domain, in other words $0 < r < 1 - C$ then the input humidity q_{in} is set to

$$q_{in} = \frac{r}{1-C}(q_{sat} - q_{min}) + q_{min}. \quad (3)$$

Since the convection scheme does not take the environmental grid-mean cloud water into account, the input humidity is set to q_{sat} if $r > 1 - C$.

It is emphasized that for each grid *column* only one random number is taken each timestep. This means that if, for instance, the random number indicates that the boundary layer parcel is taken from the driest part of the distribution, that parcel will also rise through the driest portion of each subsequent gridcell during its ascent. This assumption is essentially one of maximum overlap of subgrid-scale humidity fluctuations, but there is no reason why future work could not also investigate other overlap assumptions (e.g. Pincus et al., 2005).

One potential weakness of the above approach is that the humidity distributions are only indirectly affected by the other dynamical and thermodynamics processes. For example, in the scheme of Tompkins (2002), variance and skewness of total water are prognostic equations. Thus the occurrence of diffusion of convection directly affects these two quantities, and consequentially the shape of the underlying Beta distribution used to model the total water fluctuations used in that scheme. Here, the humidity variance is only indirectly altered through the action of other processes on the humidity, cloud water and cloud cover prognostic variables.

To confirm that this indirect diagnostic approach still renders reasonable results, fig. 3 shows maps of the RH distribution width for the two levels of 1000 hPa and 500 hPa. At 1000 hPa, the map appears reasonable, with higher variability in the tropics. One cause for concern is the apparent reduction in variance in the boundary layer Inter Tropical Convergence Zone (ITCZ), which at first appears contrary to the expectation that humidity variability would be large in a convectively disturbed environment. Further consideration reveals that this is simply due to the fact that the boundary layer humidity is quite close to saturation in these regions. It also implies that the fixed clear sky relative humidity width of 40% RH is too large, and indeed, Tiedtke (1993) imposes a more complicated formula for the critical relative humidity for cloud formation (the equivalent diagnostic assumption in that scheme) that tends from 80% towards 100% (i.e. zero width) in the boundary layer as the surface is approached. In the mid-troposphere at 500 hPa, the diagnostic approach appears to work quite well, with variability highest in the deep convective regions, and low in the subtropics and over dry desert regions. It should be emphasized that this study is intended as a pilot study to investigate the potential for such an approach, and future work would aim to link the stochastic component of the scheme directly to a prognostic statistical cloud scheme.

3 Experimentation

3.1 setup

For this initial investigation, an ensemble prediction system (EPS) experiment was conducted to investigate the impact of the stochastic convective input as outlined above. This consists of 10 day forecast integrations

turbulent boundary layer this is likely to be a poor assumption. Future developments of a scheme in conjunction with a statistical cloud scheme that models the joint probability distribution function of temperature, humidity and velocity, such as Golaz et al. (2002), will permit such cross-correlations to be entertained.

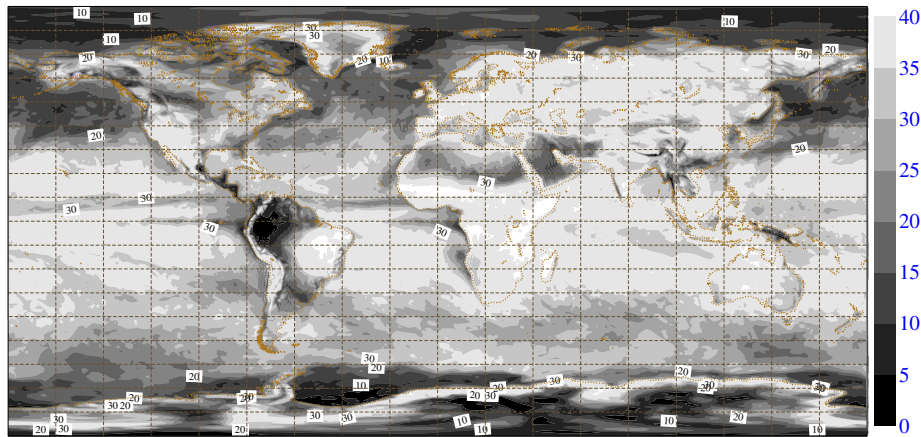
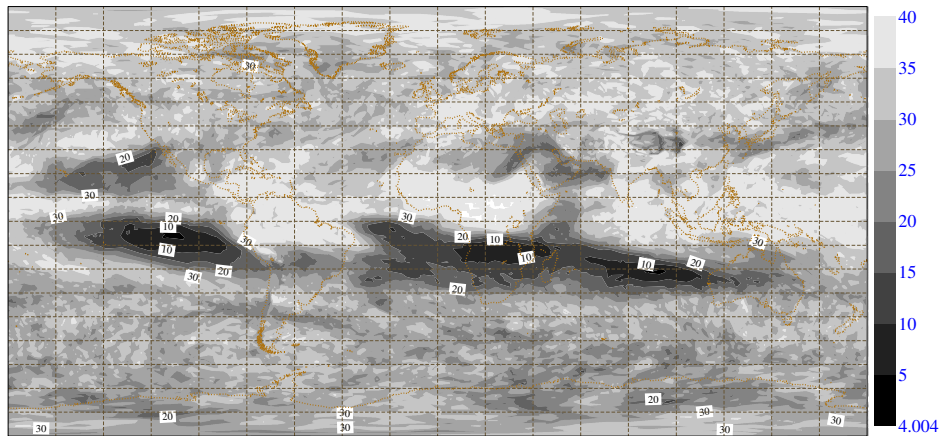
Relative Humidity Distribution Width: 1000 hPa, June 2005

Relative Humidity Distribution Width: 500 hPa, June 2005


Figure 3: Horizontal maps of the relative humidity distribution width

conducted for the first two weeks of April 2005 using a 11 member ensemble of forecasts at T255L40 resolution. The ensemble size is reduced compared to the operational system for economical testing purposes.

Two control experiments were conducted. The first control only applies perturbations to the analysis fields used to initialise each EPS model integration. These perturbations are defined by the extra-tropical and tropical singular vectors (Palmer et al., 1998). The experiment is referred to as CTRL-INIT, and it is emphasized that no stochastic physics scheme is used, the divergence between the EPS members is entirely the result of the differences in initial conditions. A second control experiment was conducted using no initial perturbations (the initial conditions are identical for each forecast) but the operational stochastic physics is applied; the experiment is named CTRL-STOCH. This operational scheme is described fully by Buizza et al. (1999) and as mentioned above, simply works by applying a multiplicative factor to the output of the physics parametrization scheme tendencies. Thus the existing operational scheme will be used as a benchmark to judge the new schemes. Additional tests using both the operational stochastic physics and the initial perturbations simultaneously confirmed previous investigations showing that the effect of the stochastic physics is much more difficult to discern in this case (the influence of the two methods on EPS spread is not additive). Thus all tests of the stochastic physics were conducted in isolation, without initial perturbations.

Three additional experiments were conducted. In the first, the subgrid-scale humidity distribution is allowed to affect the convection only above 800 hPa. Thus the properties of the test parcels raised from the boundary

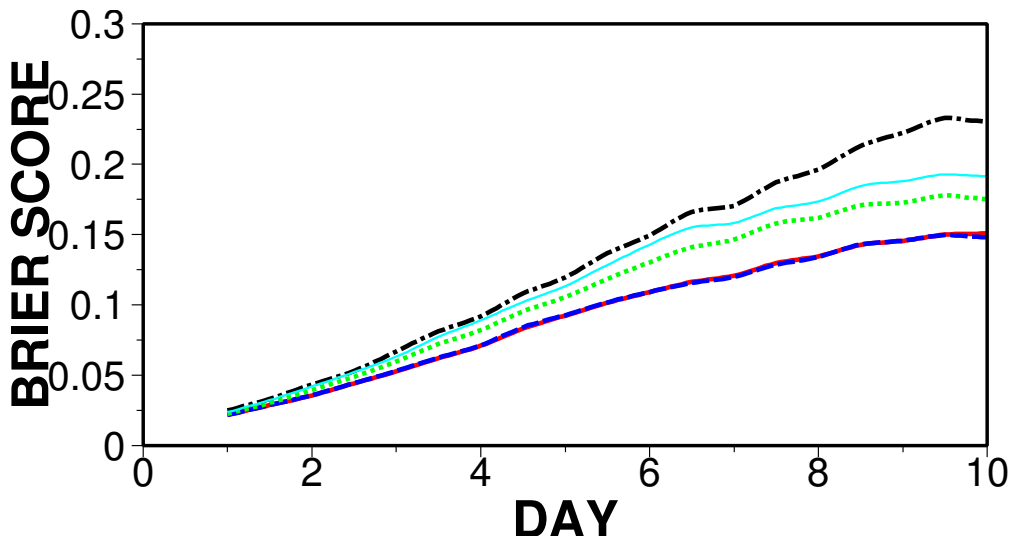


Figure 4: Brier NH scores for a negative perturbation of 0.5 hPa, for experiments CTRL-INIT (red), CTRL-STOCH (green dot), SC-FP (cyan solid) and SC-DECIDE (black dot-dash).

layer are unaffected, and only the entrainment mechanism operates. This experiment is therefore referred to as SC-ENTRAIN, where the SC denotes “stochastic convection”. In the second experiment, the convection is allowed to appreciate subgrid variability throughout the column and thus both parcel original and subsequent entrainment properties are affected. This experiment is referred to as SC-FP, where FP indicates “full profile”. In the last, the humidity information was only used in the initial decision process of whether the scheme will produce deep or shallow convection in a grid column. This latter experiment had an imperceptible affect on ensemble spread, but provides an additional useful benchmark, and is denoted SC-DECIDE.

3.2 preliminary results

To show the potential of the scheme and attempt to understand from the preliminary investigation how the ensemble spread and skill is influenced, fig. 4 gives the Brier scores (Brier, 1950) for a negative perturbation in the 500 hPa geopotential height. This is shown rather than the the more usual Brier skill score (BSS), which measures the score relative to a default forecast such as climatology, since the largest discernible differences are in the post-day 5 range, where BSS values are sub-zero for all stochastic schemes owing to the lack of initial perturbations, the small ensemble size and relative harshness of the climatological test (Kumar et al., 2001; Mason, 2004).

The four curves compare the experiments SC-DECIDE, SC-FP, CTRL-STOCH and CTRL-INIT. In fact the plot contains a fifth curve (blue dashed) demarking the experiment with both the operational stochastic physics *and* the initial perturbations, but it exactly overlays the experiment CTRL-INIT, confirming that with singular vector provided initial perturbations, no additional impact results from the use of the operational stochastic physics scheme in this forecast range for this metric.

Comparing the four main experiments, and recalling that SC-DECIDE had minimal impact on forecast spread, it is seen that the new scheme SC-FP has a smaller but comparable impact in the Brier score to the operational stochastic scheme at the day 10 range. However, if the earlier forecast range is examined closely, it is noted that, unlike CTRL-STOCH, the new scheme has little effect before day 4. The reasons for this become clear when maps of ensemble spread are examined; here maps of the 700hPa temperature spread are shown, but the conclusions drawn are also generally valid. Figure 5 gives the 2-week average 700 hPa RMS temperature error of the control forecast at day two, the forecast range for which the initial perturbations are tuned. This is shown

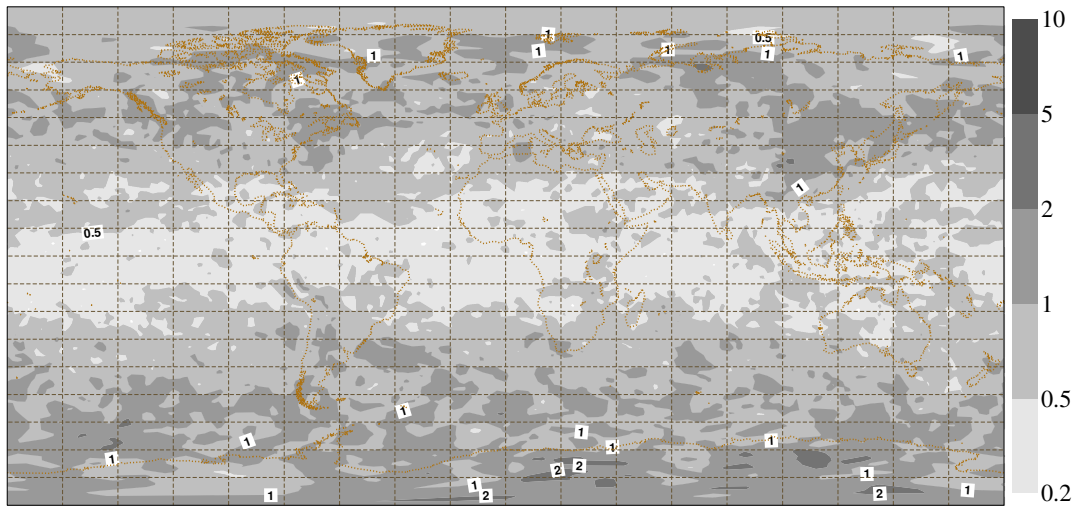


Figure 5: Day 2 RMS error in 700 hPa temperature averaged over 2 weeks of forecasts for the first half of April 2005 from the ensemble control

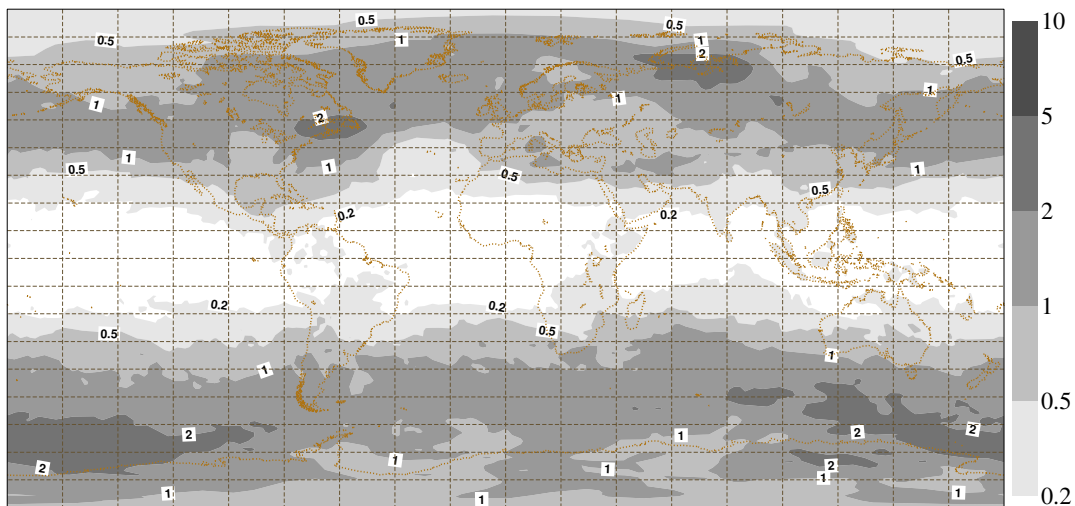


Figure 6: Day 2 inter-ensemble “spread” (RMS differences) in 700 hPa temperature for CTRL-INIT averaged over 2 weeks of forecasts for the first half of April 2005

merely as a benchmark since, ideally, one would desire ensemble spread to be of a comparable magnitude to this error. Errors are mostly in the 0.5 to 2 K range throughout much of the extra-tropics, while smaller errors are seen in the tropics.

In comparison, fig. 6 gives the ensemble spread of the same variable for CTRL-INIT at the day 2 range, averaged over the same two weeks. The spread is quite uniform in the extra-tropics, of a comparable magnitude to the RMS error, but generally larger, in the 1 to 2K range, and in many regions even exceeding the 2 K threshold. When the control mean RMS error and CTRL-INIT spread are compared at later forecast ranges, this situation reverses, with the spread in the latter smaller than RMS errors. This behaviour is well known (e.g. see figure 8 of Shutts, 2004) and was one of the original motivations for the development of the stochastic physics scheme. Almost no spread is observed in the tropics in CTRL-INIT, as expected since the tropical singular vectors are designed to target tropical cyclones, and are completely inoperative if no such systems are

detected.

Figure 7 shows the spread for CTRL-STOCH, and it is clear that the magnitude in the extra-tropics is considerably smaller than CTRL-INIT, with the spread mostly limited to less than 0.5 K at day 2. At this forecast range the impact is fairly uniform throughout the tropics and extra-tropics.

Considering the new schemes, experiment SC-ENTRAIN produces little impact (Fig. 8), with spread less than 0.2K throughout most of the tropics and extra-tropics. The interesting point is that the regions where additional spread is seen correspond to the regions of tropical continental deep convection over South America, Africa and southeast Asia. As the forecast progresses, sensitive regions of enhanced spread that coincide in location in both SC-ENTRAIN and CTRL-STOCH become notable. For example in the SH off the southern tip of the African continent, and over Canada there are regions of enhanced spread at day 5 (not shown). It appears that any kind of reasonable perturbation is enough to capture the forecast uncertainty in these locations, considering the very different mechanisms used in SC-ENTRAIN and CTRL-STOCH.

When the full-profile is perturbed, rather than just the free troposphere, (SC-FP in Fig. 9) the picture changes considerably. The magnitude of the spread in the extra-tropics is smaller, lying between 0.2 and 0.5 K, than that resulting from the use of singular vector initial perturbations, but is comparable to the operational scheme CTRL-STOCH. However, the more striking feature is the much bigger impact in spread uniformly throughout the tropics. The spread in the tropics is larger than the RMS error at day 2 (recall fig. 5). Unlike SC-ENTRAIN the impact is similar for both oceanic and land-based tropical deep convection and is also considerable in the shallow convection regions. One reason for this could be that the mid-tropospheric moisture profile tends to be drier over the tropical continents, which could increase the role of mid-tropospheric perturbations there.

When maps of spread are examined for forecast ranges of 5 and 10 days, (Fig. 9b,c), it is seen that, while the main impact of SC-FP in the short, day 0-3, range is in tropics, as one would expect since the influence acts through deep convection, in the medium range the influence is seen to spread to the midlatitudes. This explains the negligible impact of NH Brier scores in the short term documented above, with increased impact later in the forecast in the extra-tropics.

Finally, we note that examination of the model climate averaged over longer 13 months integrations (see Tompkins et al., 2004, for details of setup) that convective precipitation is substantially reduced (by approximately 20%) by the implementation of the stochastic physics package. Some of this reduction is compensated for by a commensurate increase in large-scale precipitation, indicating a greater occurrence of grid-scale convection. This will require further investigation to establish the influence on the hydrological cycle. The changes also produce smoother precipitation fields, giving an improved agreement with GPCP data in the tropics (not shown). It is interesting to note that the scheme outlined by Shutts (2004) also had a large impact on the hydrological cycle, with a significant reduction in tropical rainfall noted (Jung, personal communication).

4 Conclusions

This work has outlined a preliminary investigation of a convective stochastic physics scheme, whereby the input profile of humidity provided to the convection scheme is not simply the grid-mean value, but instead is randomly sampled from an underlying distribution that accounts for subgrid-scale variability. Thus the forecast uncertainty is able in some way to account for knowledge of humidity fluctuations on scales below the truncation scale of the model. Ideally the variance of the humidity distribution, determining the magnitude of the perturbations around the mean state, would be directly linked to the local dynamical and thermodynamical conditions by the implementation of prognostic statistical cloud scheme of the type outlined by Tompkins (2002). However, since the ECMWF IFS does not currently have such a scheme, the underlying distribution was determined from, and consistently with, the prognostic variables of humidity, cloud water and cloud water. Thus the dynamical processes such as turbulence that affect these latter prognostic quantities will also affect the humidity fluctuations indirectly.

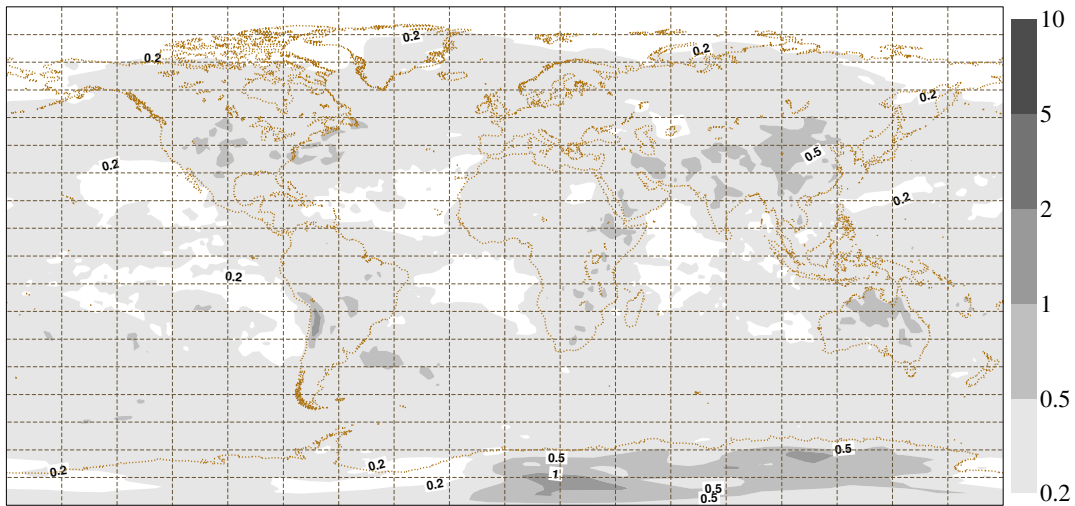


Figure 7: As fig. 6 but for CTRL-STOCH

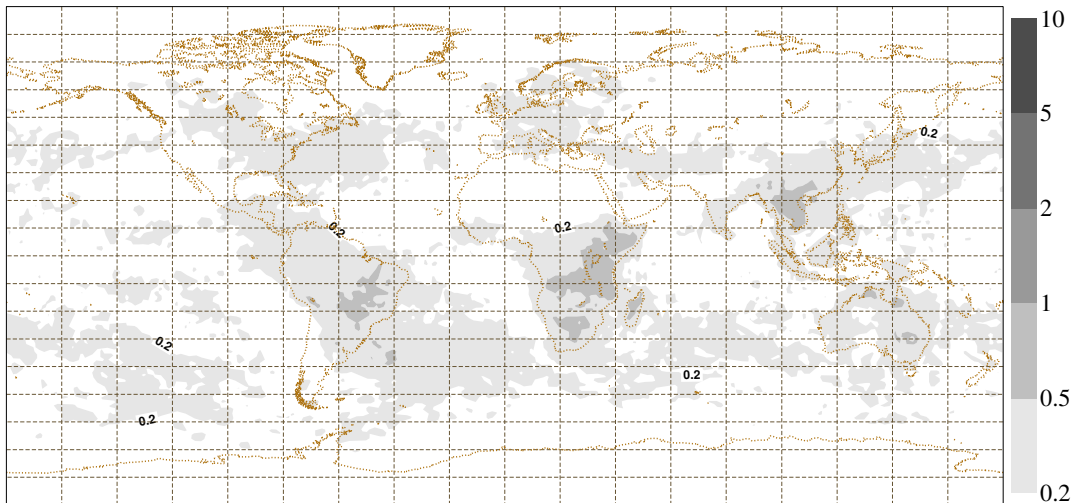


Figure 8: As fig. 6 but for SC-ENTRAIN

The stochastic scheme was introduced into the ECMWF EPS system, and preliminary tests showed that the humidity variability has much more importance in the boundary layer, determining the convective test parcel's original properties, than above the boundary layer where it affects the convective mass fluxes by its influence on entrainment. This agrees with the findings of Tompkins (2001). The influence of the full scheme, where both the boundary layer and free tropospheric humidity profiles are perturbed, was found to be less than but of comparable magnitude to the operational stochastic physics scheme in the extra-tropics, but only in the medium range past day 4 to 5 of the forecast. In the short range the extra-tropical influence was negligible. This was found to be due to the fact that the scheme has most influence in the tropics, perhaps as expected since it acts solely through deep convection. This is encouraging since the current stochastic physics scheme has less influence in these regions. The influence spreads from the tropics to midlatitudes in the medium range. However, a cautionary note was signalled since the scheme was found to have a significant impact on the model mean climate, unlike the operational stochastic physics scheme. Much further investigation and refinement will be needed to produce a workable scheme from this framework, however the results of this preliminary investigation indicate that a reasonable spread of forecast attributes can be obtained from a physically based perturbation of the convective scheme.

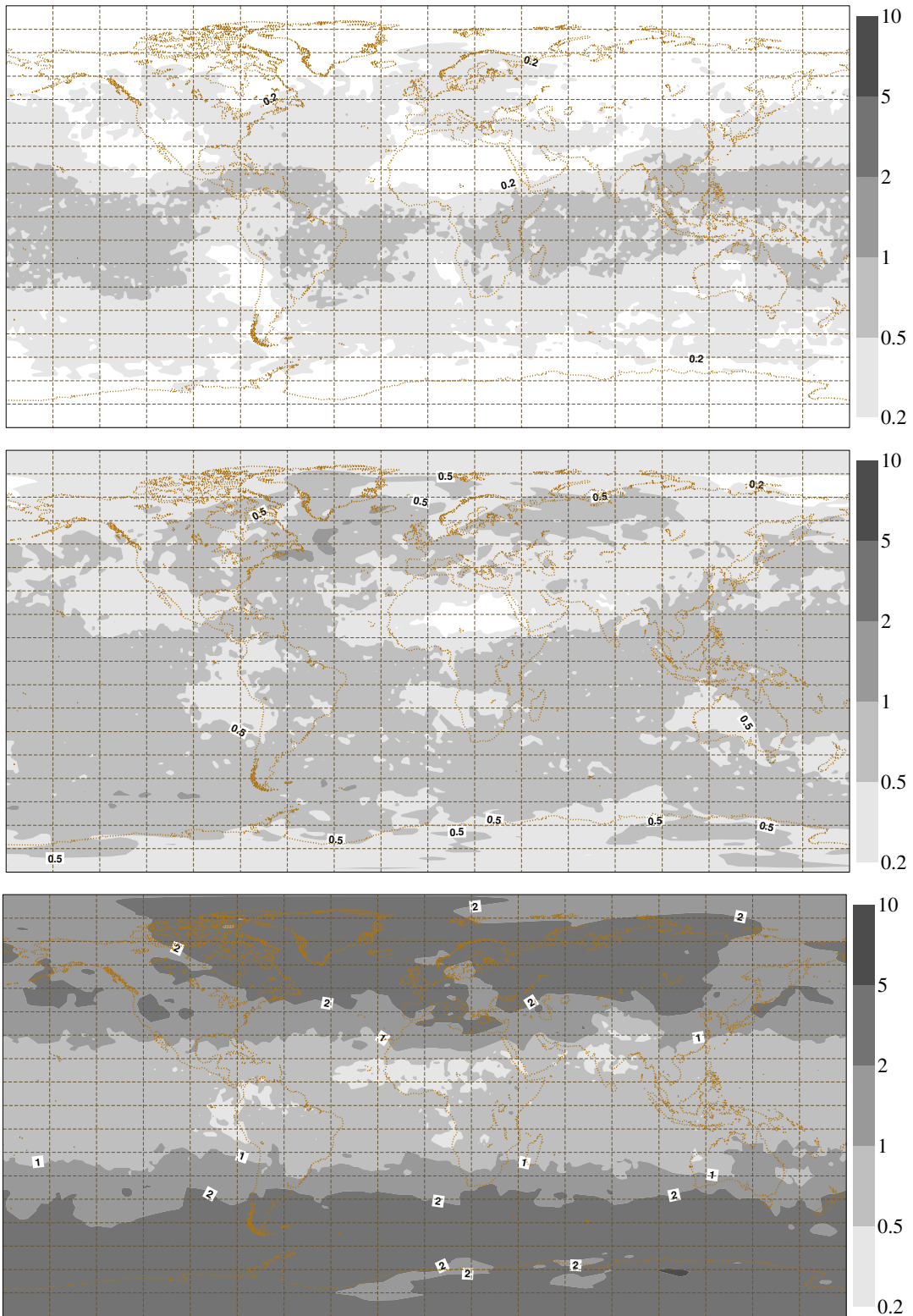


Figure 9: As fig. 6 but for SC-FP at forecast ranges of (top) 2, (middle) 5 and (bottom) 10 days

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