9.6 Convective Precipitation

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Convective Precipitation

In the current configuration of the convection scheme any showers that are developed are considered to remain within the column and fall vertically downwards. This has serious consequences when forecasting shower activity.

Users should be aware of:

1. **Limitations of the portrayal of convective precipitation:**
   - Precipitation is the grid box average value, not a point value. Detail is lost within the grid box due to sub-grid variability, particularly in convective situations when the individual showers might be heavy but the displayed average precipitation is low.
   - Localised extreme values in precipitation totals are systematically underestimated in IFS output because of the resolution, and also the related parametrisation of convection. Differences of about one order of magnitude are possible although verification that integrates totals over areas that are the same size as the effective grid box size suggests the agreement is generally much better. Convective precipitation has greater sub-grid variability than large scale precipitation.
   - Only rain or snow is produced by the precipitation scheme. Hail is not considered nor developed in the IFS convection scheme, no matter how unstable is the model atmosphere.

2. **The effects of non-advection of showers by the convective scheme:**
   - Convective precipitation falls out immediately, vertically downwards, as soon as convection is diagnosed (in contrast to hydrometeors classed as large-scale which follow a wind-dependant path down through the atmosphere). Drifting of convective particulate as it falls is not represented in the IFS. In reality rain drops or snow flakes are likely to be blown downwind a distance proportional to:
     - the fall-speed of the hydrometeor (rain higher fall-speed, snow low fall-speed),
     - the low-level wind strength.
   - Convective cells do not have a finite life cycle in the IFS - in effect the lifetime is zero with the model atmosphere instantly resetting itself. In the real world showers retain some integrity in terms of their vertical circulations beyond their triggering point and this is not really represented in IFS. The exception to this is when convection becomes so organised on the gridscale that large scale precipitation is diagnosed.
   - The net effect of the two aspects above is that in the IFS one tends to see discontinuities in convective precipitation at the coastline. Near to coastlines precipitation totals, whereas in reality totals in convective situations (as seen via radar-based accumulations) generally cross coastlines unimpeded. Therefore precipitation totals downwind of the coastline are often under-forecast. This can be:
     - where land-based convection moves out over the sea (daytime), and
     - where marine-based convection moves inland (any time)
   - Errors extend across larger distances when the wet-bulb freezing level is low, when winds are strong, and when convection is deep and active

3. **Potential for anomalous convective development:**
   - Over-active convection in the tropics is occasionally produced in the very short-range (e.g. between T+0 and T+6). In consequence, anomalous forecasts of precipitation totals can be indicated in adjacent areas.

Model improvements related to modelling non-equilibrium convection
Equilibrium convection (or quasi-equilibrium convection) considers forcing due to mean advection and to processes other than convection. It is used by many numerical models and has been found to be valid for synoptic disturbances and for time-scales of the order of one day. However, deep convection, largely driven by the diurnally varying surface heat flux, generally begins too soon in the morning and ceases too readily in the evening. This used to be used in the ECMWF IFS.

Non-equilibrium convection considers forcing varying on time scales of a few hours rather than diurnal changes. It takes into account that not all boundary layer heating is available for conversion into deep convection, but only a fraction that varies through the day. During the morning and noon, most of the heating induces dry and shallow non-precipitating convection while only later does it release deeper, more active convection as convective inhibition is overcome. A way of modelling this was introduced operationally into the IFS in November 2013.

The intrinsically slower convective adjustment produces:

- a somewhat more realistic diurnal cycle of convection over land,
- better temporal and spatial distribution and local intensity of showers,
- an improved diurnal cycle in coastal regions,
- a slightly more realistic penetration of convective precipitation inland from coasts concurrent with a reduction in unrealistically heavy precipitation at the coast itself.

Night-time convective precipitation remains underestimated.

Some examples are given below of the effects of non-advection of showers by the convective scheme.

Fig9.6.1: This old example was with "equilibrium convection", that is no longer present in the IFS: 30h convective precipitation totals (mm) with mean sea level pressure verifying at 18UTC 29 Nov 2010, forecast data time 12UTC 28 Nov 2010. The convection scheme is diagnostic and works on a grid box column, so cannot produce large amounts of precipitation over the relatively dry and cold (stable) wintery land areas. Showers are shown as limited to the sea alone while in nature these showers penetrate inland on the brisk easterly wind.
Fig 9.6.2: This newer example was with non-equilibrium convection, introduced into the IFS in 2013: precipitation fields when showers developed over the Great Lakes in very cold air on a westerly wind (mm rainfall equivalent). Significant showers are shown where strong convection is initiated over the relatively warm waters of the Great Lakes, but give very small amounts of showery precipitation down-wind where instability is not initiated over the cold land. In reality the showers developing over the Great Lakes persisted long enough to be blown well inland as active convection. Note in particular the difference in precipitation east of Lake Michigan.
Convective Severity - CAPE and CAPE-shear

Convective Available Potential Energy (CAPE) can be a guide to the intensity of convection, but only if convection triggers. At any given grid point the convection scheme inspects the temperature structure of the model atmosphere progressively from the surface to 300hPa and if there exists a level of free convection (LFC) it evaluates the CAPE. Entrainment of surrounding air is not considered and thus the evaluated CAPE is likely to be a slight overestimate. The search for CAPE currently in use facilitates discovery of elevated instability, even at night when there will often be low-level stability. Convective Inhibition (CIN) is assessed from the model atmosphere in a similar way. The CAPE-shear parameter (a combination of bulk shear (vector wind shear between 925hPa and 500hPa) and CAPE in the model atmosphere) is used to identify areas of potentially extreme convection. CAPE and CAPE-shear, and associated probabilities and Extreme Forecast Indices (EFIs) and Shift of Tails (SOT) plots are available as static web plots and within eCharts. Some indication of how extreme localised precipitation totals can be can be deduced from the values of CAPE and CAPE-shear, taking into account also whether or not significant rainfall intensities are forecast and/or whether the upper contour pattern favours mass uplift.

Note: Hail is not considered nor developed in the atmospheric model convection scheme, no matter how unstable is the model atmosphere. Only rain or snow is produced by the precipitation scheme.

The following set of figures relates to a winter-time case over Northern Italy / Alpine regions:
Fig 9.6.4A (left): Forecast CAPE Extreme Forecast Index (EFI) in northern Italy and western Austria for 00UTC 12 to 00UTC 13 Dec 17, T+24 to 48 from data time 00UTC 11 Dec 17. The darker orange area over far North Italy and Tyrol (roughly shown by the pin) has EFI>0.8 denoting high probability of an out-of-the-ordinary significant event. EFIs are shown by colours - Yellow >0.5%, Dark Yellow >0.6%, Orange >0.7%, Dark Orange >0.8%, Red >0.9%.

Fig 9.6.4B (right): Forecast CAPE-shear Extreme Forecast Index (EFI) in northern Italy and western Austria for 00UTC 12 to 00UTC 13 Dec 17, T+24 to 48 from data time 00UTC 11 Dec 17. The red area over far North Italy and Tyrol (roughly shown by the pin) with EFI>0.9 and is rather larger in extent than CAPE EFI owing to the influence of the bulk shear in the lower troposphere. EFIs are shown by colours - Yellow >0.5%, Dark Yellow >0.6%, Orange >0.7%, Dark Orange >0.8%, Red >0.9%. 
Fig 9.6.5A (left): Forecast probability of precipitation (>5mm/12hr) in northern Italy and western Austria for 12hr period ending 00UTC 13 Dec 17. T+36 to 48 from data time 00UTC 11 June 17. Higher probability of precipitation over Tyrol. Probabilities shown by colours - Light blue >5%, Blue >35%, Dark blue >65%, Purple >95%.

Fig 9.6.5B (right): Forecast CAPE-shear EFI superimposed upon forecast probability of precipitation (>5mm/12hr) in northern Italy and western Austria ending 00UTC 13 Dec 17, T+48 from data time 00UTC 11 June 17 as figures shown above. High CAPE or high CAPE-shear alone show only the potential for active convection - if it can be released. It is also necessary to identify where the atmospheric model is actually producing precipitation, and if this overlaps with high CAPE or CAPE-shear then severe convection may be forecast. In this example the area over far North Italy and Tyrol (roughly shown by the pin) has high CAPE-shear and high probability of precipitation and hence severe weather may be forecast in the area.
In such a winter case the values of CAPE and CAPE-shear are unlikely (inland) to be dramatically large, particularly when compared to summertime values. But nevertheless, the EFI values for CAPE (Fig9.6.4A) and especially CAPE-shear (Fig9.6.4B) are high, indicating the forecast values are towards the high end of the M-climate distributions for these parameters, and are therefore worthy of further investigation. In particular, there is an enhanced likelihood that the convection scheme’s totals may not be so representative and that much more extreme local totals are possible.

Observations available for this case suggested quite a lot of localised variability, though peak 24h totals were no more than 20mm. It may be that although the CAPE-shear EFI was anomalously large, the absolute values of CAPE-shear may not have been very high.

**Consideration of the impact of differing land surfaces.**

Land surface characteristics (soil moisture, leaf area index) have an impact upon land and temperature forecasts. Changes in land characteristics is especially important where there is a sharp discontinuity in ground type or cover by vegetation. This can produce significant difference in temperatures or moisture content of the lower atmosphere over a short distance, and hence to air temperature and/or the development of convection. Users should inspect model information on land surface, soil moisture and leaf area index to identify areas where significant changes in precipitation or other weather phenomena over short distances may occur.
Fig 9.6.7: Illustration of the impact of differing land cover and type in the vicinity of Flagstaff, Arizona. Showers broke out over the vegetated west part of the area but not over the rocky region to the east. The ENS 98th percentile of “point rainfall” (an ECMWF product introduced into ecCharts in April 2019) and tephigrams for T+24 based on data time 00UTC 18 July 18 is shown in the central diagram. Partly due to altitude, but also due to differences in Humidity Mixing Ratio, the parcel curves have very different CAPE values - more in the west hence greater risk of very wet weather, but less in the east even though temperatures were higher over the bare surface. This illustrates high sensitivity to humidity mixing ratios (and altitude). In turn humidity mixing ratios can reflect land surface processes related to evapotranspiration which control the moisture exchange with the lower troposphere. And in turn these relate to the soil moisture which controls moisture availability. Also of critical importance on the soundings are the light winds with shear. Here the land surface characteristics changed rapidly across a short distance (forest to rock), which is in fact reflected on the deep (1m) soil moisture plots from the IFS, and also in the leaf area index (LAI), which is a multiplying factor for evaporation.

Consideration of the impact of low-level moisture.

The release of convection is strongly dependent upon correct analysis and forecasting of boundary layer humidity and land surface characteristics. This can result in a mismatch, mainly in arid coastal regions, between the location and/or severity of forecasts of active convection and the corresponding observations. Showers may be forecast in the wrong location or not forecast at all. Users should consider the possible effects of more moist air feeding into the boundary layer, perhaps by considering the potential for moist marine air to spread inland in a more pronounced way than HRES forecasts suggest. Users should consider the possibility of an influx of low level air that is dissimilar to forecast values - i.e. moist air across coastal areas that might allow release of convection, or the converse if an influx from drier areas occurs. Daytime heating at higher locations and/or upslope flow over the mountains can also cause destabilisation that may not be captured by the forecast models.

Fig 9.6.8: Large and vigorous convection over eastern Oman 6 July 2018 bringing heavy showers.
Fig 9.6.9: Observed (black) and forecast (red) vertical profiles at approximately the same time as the satellite picture (Fig 9.6.8) for a radiosonde location (Seeb, WMO:41256) just northwest of Muscat. The lowest layers were observed to be quite moist while the forecast vertical profile indicated much drier conditions. The low level winds are shown as drifting air from the nearby sea on both observed and forecast profiles. Higher moisture at low levels would allow deep and active convection to be released with sufficient energy input to overcome the convective inhibition (CIN), either by surface heating or by uplift over the mountains. Heavy showers did develop but were not well forecast, if at all.

Considerations related to extreme convection

HRES tends to over-forecast extreme convection, especially in the maritime tropics. Spurious quasi-circular waves (sometimes rings) in convective precipitation fields can emanate from the forecast rapid uplift that is associated. These spread outwards. The gravity waves can even move well upwind, giving a false impression of an eastward-moving trough. The source of these false features should be recognised and their effects discarded from forecasts. Changes to the IFS moist physics in 2019 will mitigate (but not entirely remove!) this effect.

Fig 9.6.10: An example of a forecast precipitation chart showing a very active convective area in the mid-Indian Ocean. The surrounding ring of forecast precipitation is associated with a spurious gravity wave (ripple effect) moving outward from the initial convective cell. These rings of precipitation are incorrect and should be ignored.
Fig 9.6.11: HRES forecast of precipitation associated with gravity waves propagating outward across central Africa from a pulse of very strong convection formed over the Gulf of Guinea (just to the southwest of the charts). Model precipitation rate are shown for one such feature at T+120, T+132, T+144, data time 00Z 3 Sept 2018. The apparent trough is propagating anomalously against the flow and the precipitation is not correct.

Additional Sources of Information

(Note: In older material there may be references to issues that have subsequently been addressed)

- Read more on the Convective Scheme in the Atmospheric Physics page (scroll down to the subsection: Convection).
- Read more on the Convective Scheme (Quasi-Equilibrium and Non-Equilibrium Convection) in Breakthrough in Forecasting Convection.
- Read more on Atmospheric Moist Convection.
- Read more about the EFI parameters for Severe Convection.
- Read more on Early Warnings of Severe Convection using the ECMWF Extreme Forecast Index.
- Watch a comprehensive lecture on Model Physics (30sec delay before video begins). The convection parameterisation scheme is considered in the lecture between 36min45sec and 40min45sec. Penetration inland of showers is considered in the lecture between 45min20sec and 46min50sec.
- Watch a comprehensive lecture on model clouds and precipitation (25sec delay before video begins).

Updated/Amended 30/12/19 - Link to issue with CIN

Updated/Amended 02/07/20 - Removed link to issue with CIN. Not applicable with 47R1.