Impact of Climate Change on Irish Agriculture

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1. Introduction

If emissions of greenhouse gases continue to increase at current rates, a doubling of atmospheric concentrations of CO_2 is likely to occur by the end of the present century. An increase in effective CO_2 is likely to occur much sooner. Global climate model (GCM) simulations of the climate system suggest that increases in global temperature in the order of between 1.8 to 4.0°C by 2100 are likely as a consequence (IPCC,2007). These temperature increases are unlikely to be uniformly distributed and there is likely to be a large degree of regional variation in the spatial distribution of these increases. Future projections of climate suggest that:

- Globally averaged surface temperature is likely to increase by between 1.8 to 4.0^{o}C, over the 1990 to 2100 period, depending on emissions scenarios (Figure 1).
- Precipitation increases are likely by the middle of the present century in the mid to high latitudes in winter, with large year-to-year variations.
- An increase in maximum temperatures and in the frequency of hot days is very likely.
- More intense precipitation events are also very likely over mid to high latitude areas of the Northern Hemisphere
- The present day retreat of mountain glaciers is likely to continue during the course of the 21st century. While Antarctica is likely to gain mass due to enhanced precipitation, Greenland is likely to lose mass due to a greater increase in runoff over precipitation increases.
- The best estimate for global mean sea-level rise over the present century is 0.48 metres. Sea-levels are likely to continue to rise after 2100.

2. Climate Change and Ireland

2.1 Global Climate Models

Model projections of future climate are highly dependent on future estimates of greenhouse gas concentrations and aerosol loadings in the atmosphere. These cannot be forecast with a high degree of confidence for decades ahead, and yet this must be attempted if any modelling of future temperature and rainfall is to have credibility. To address this major uncertainty the Intergovernmental Panel on Climate Change commissioned a study to provide a range of plausible future socioeconomic scenarios which could be equated to particular atmospheric loadings of greenhouse gases and aerosols. Generally these reflected much reduced aerosol sulphate loadings from earlier efforts, reflecting growing control of these emissions on the part of the industrialised world. The consequence of this was that the cooling influence of aerosols was diminished in most GCMs and global warming estimates increased sharply in the Third Assessment Report. A range of 'storylines' was produced of which four 'marker' scenarios were used to drive GCMs (Figure 2).

The A2 and B2 scenarios were selected for this study of Irish climate scenarios. For the A2 emissions scenario the main emphasis is on a strengthening of regional and local culture. A very heterogeneous world is envisaged with large disparities in wealth and well being. Population growth is high with global population reaching 15B by 2100. Economic and technological growth is less dramatic. Per capita income is slow to increase and less emphasis on environmental protection than the other scenarios is apparent. Its CO_2 emissions are the highest of all four scenario families (Figure 3).

The B2 world sees population reaching about 10 billion people by 2100. This is in line with both the United Nations and IIASA median projections. Global per capita income grows at a moderate rate to reach about US$12,000 by 2050. The divergence in incomes between rich and poor nations decreases, although not as rapidly as in scenarios of higher global convergence (A1, B1). Although globally the energy system remains predominantly based on oil and gas to 2100, there is a gradual transition to renewables with a gradual

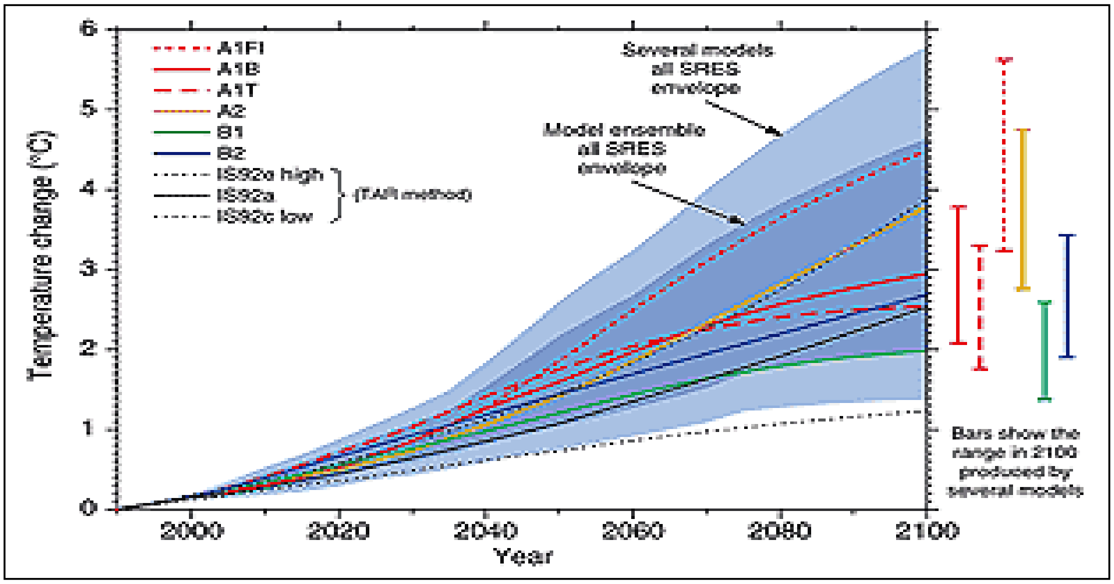


Figure 1. Projected Temperature Changes with various emmission scenarios (Source: IPCC, 2001)

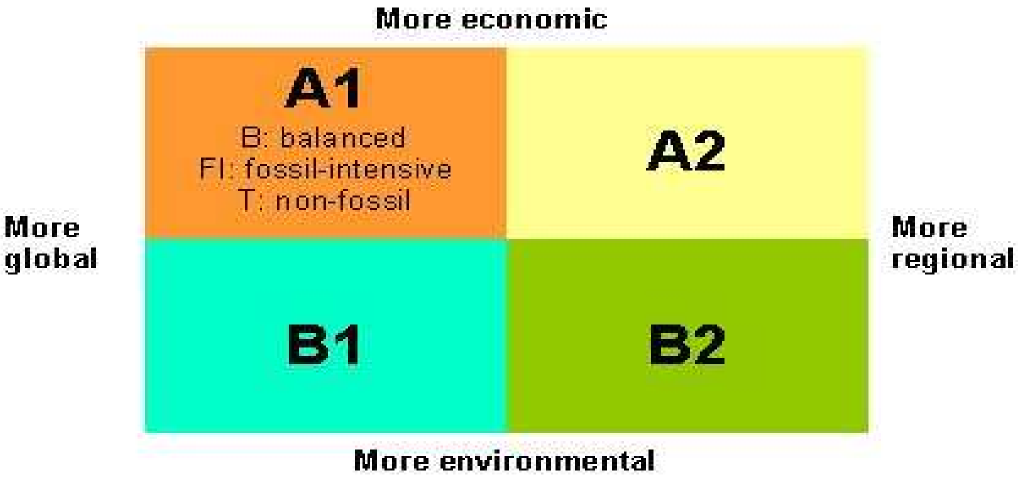


Figure 2. The Special Report on Emissions Scenarios (SRES) of the IPCC

decoupling of energy production and greenhouse gas emissions.

An increase in global temperatures of the magnitude projected by GCMs is likely to have a significant impact on climate processes operating at various scales, from global and hemispherical scale processes to the regional and local scale surface environmental variables. Confidence in the simulations of these models is largely based on the assumptions and parameterisations used to develop them but also on the ability of these models to reproduce the observed climate (Karl *et al.*, 1990). In recent years increasing sophistication of these models has resulted from an improved understanding of the underlying climate process and ability to incorporate these advances into these numerical models. Complexity of the climate system is also accounted for with the incorporation of horizontal and vertical exchanges of heat, moisture and momentum extending into the atmosphere and ocean

2.2 Downscaling

Despite the high degree of sophistication of GCMs, their output is generally too coarse to be useful for regional or local scale impacts analysis, as important processes which occur at sub grid scale are not at present resolved by these models (Wilby *et al.*, 1999). Changes in both temporal and spatial variability which may be just as important as the magnitude of change, are also masked at the sub grid scale (Wigley *et al.*, 1990), as it is unlikely that all locations will warm by the same amount and at the same rate. Global variations in the amount and rate of warming will also affect the distribution and rates of change of other meteorological variables, such as precipitation. Therefore a disparity of scales exists between the global scenarios, as output by GCMs, and changes that could occur at the regional or local level due to these large-scale changes. In order to overcome some of these scale differences, a number of techniques have been developed in which large-scale GCM output can be translated or ‘downscaled’ into information about changes in the climate which can then be used for local scale impact analysis.

2.2.1 Regional Climate Models

The application of regional climate models (RCMs), which are dynamic in nature, to the downscaling problem have become more widespread in recent years due to the increase in available computational resources. RCMs are fundamentally similar to GCMs in that they utilise physical parameterisations that are either consistent to their respective resolutions or each other (Yarnal *et al.*, 2001). Their added value is derived from the fact that they operate on a much smaller domain and as such offer a much higher resolution than that of the parent GCM within which they are nested. The optimum resolution at which nested RCMs operate is in the tens of kilometres, which may still be too coarse for some impacts analysis needs.

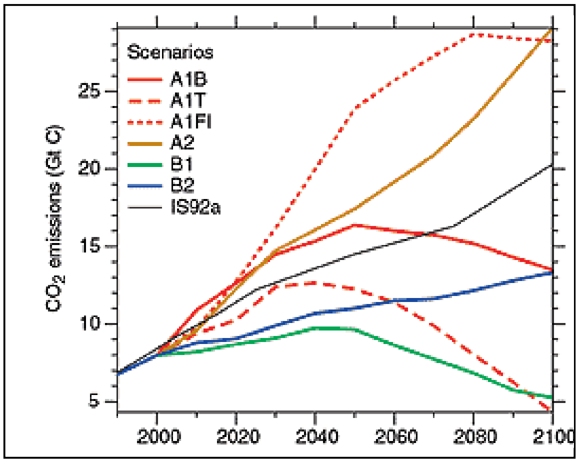


Figure 3. Carbon Dioxide (CO_2) emmissions, 1990-2100, for seven marker emmisions scenarios

(Source: IPCC (2007)

2.2.2 Empirical Statistical Downscaling

Empirical statistical downscaling has become a viable alternative to that of RCMs where high spatial and temporal resolution climate scenarios are required. It requires substantially less computational resources and produces results that are comparable to that output from RCMs. The methodologies employed in statistical downscaling are largely in common with those of synoptic climatology, however, the goal of downscaling is to adequately describe the relationship between atmospheric circulation and the surface environment, with attention being focused more on model parsimony and accuracy, rather than understanding the relationship between them (Yarnal *et al.*, 2001). As a consequence of their relative ease of implementation and comparability of output to RCMs, the use of statistical downscaling methodologies to produce climate scenarios from GCMs is now the favoured technique for many researchers.

Empirical statistical downscaling is based on the development of mathematical transfer functions or relationships between observed large-scale atmospheric variables and the surface environmental variable of interest. The transfer functions are generally regression based and are derived between a set of atmospheric grid scale predictors, output from both reanalysis projects and GCMs, and a single predictand. However, a large number of techniques fall in to the category of empirical statistical downscaling.

The use of statistical downscaling requires that a number of assumptions are made, the most fundamental of which assumes that the derived relationships between the observed predictor and predictand will remain constant under conditions of climate change and that the relationships are time-invariant (Yarnal, 2001). It also assumes that the employed large-scale predictor variables are adequately modelled by the GCM for the resultant scenarios to be valid. Busuioc *et al.* (1998), in their verification of the validity of empirical downscaling techniques, found that in the case considered, GCMs were reliable at the regional scale with respect to precipitation in their study area and that the assumptions of validity of predictor-predictand relationship held up under changed climate conditions.

Observed daily data for precipitation, temperature and sun hours were obtained from 14 synoptic stations from the Irish meteorological service, Met Éireann, for the period 1961-2000. Potential evapotranspiration, based on the Penman-Montieth formula, was obtained for the 1971-2000 period, while radiation, for the 1961-2000 period, was only available from a selection of synoptic stations. The synoptic stations, which are geographically dispersed around the island, represent low-lying conditions for a mixture of coastal and interior locations (Figure 4). No prior homogeneity analysis of the daily data was performed. However, the data obtained are from the synoptic network, manned by experienced meteorological officers, and are considered to be of good quality. The data are, however, provided with quality control flags, indicating whether the measurement is the value as read, accumulated, trace or otherwise, therefore enabling the researcher to decide on a suitable threshold for accepting the data as valid. In the present research, all values not directly measured by the observer were removed from the analysis, with the exception of potential evapotranspiration which is a calculated variable.

Large-scale surface and atmospheric data were obtained from the UKSDSM data archive (Wilby and Dawson, 2004), derived from the NCEP/NCAR Reanalysis project. The NCEP/NCAR data, originally at a resolution of 2.5^o x 2.5^o degrees, were regridded to conform with the output resolution of the HadCM3 GCM. Prior regridding of the reanalysis data is important in order to overcome any mismatch in scales that may exist between predictor datasets. Standardised reanalysis variables, as advocated by Karl *et al.* (1990), were then used as candidate predictor variables to calibrate the transfer functions, linking the large-scale surface and atmospheric variables to the daily precipitation series for each of the 14 synoptic stations. Even though the reanalysis data are essentially modelled data, they are constrained by observational data from the global monitoring network and are a modelled, gridded replicate of the observed data. Relationships between grid box values, representing Ireland, for a selection of variables from the reanalysis data were found to be significantly correlated with that of the actual observed upper air variable measured at the two upper air stations in Ireland, Valentia in the south west and Aldergrove in the north.

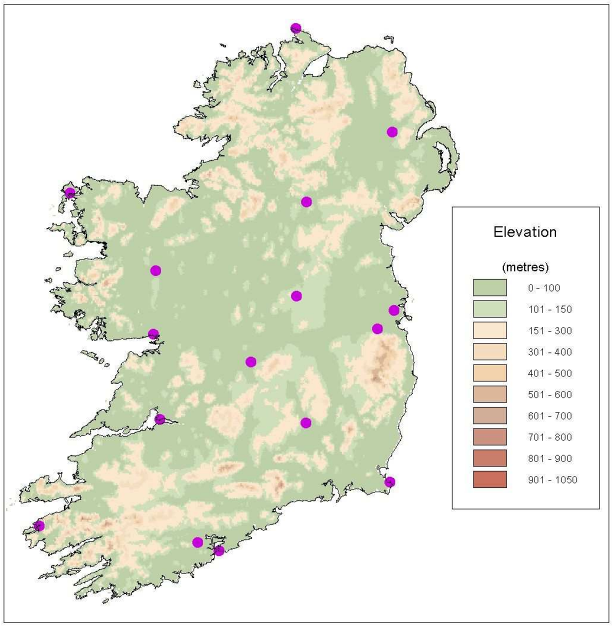


Figure 4: Location of synoptic stations

In order to derive the future climate scenarios based on the transfer functions, GCM data were obtained, again from the UKSDSM archive, for three models, namely the Hadley Centre (HadCM3), Canadian Centre for Climate Modelling and Analysis (CCCma) (CGCM2) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO Mark 2), for both the A2 and B2 emissions scenarios (Wilby and Dawson, 2004). All the modelled gridded datasets exist on a common grid resolution, that of 2.5^o x 3.75^o degrees, and were obtained for the grid box representing Ireland in the GCM domain. The lead and lag of each predictor was also calculated to allow for NCEP daily averaging (0000-2400 hours) and reporting of daily precipitation (0900-0900). Employed lagged variables as predictors also allows for a temporal lag which may occur between the predictor and predictand.

2.3 Climate Scenarios for Ireland

The stations showing the largest change and the smallest change in temperature for the different GCMs are illustrated in Figure 5 for each of the three time periods and season for the A2 emissions scenario. In general,

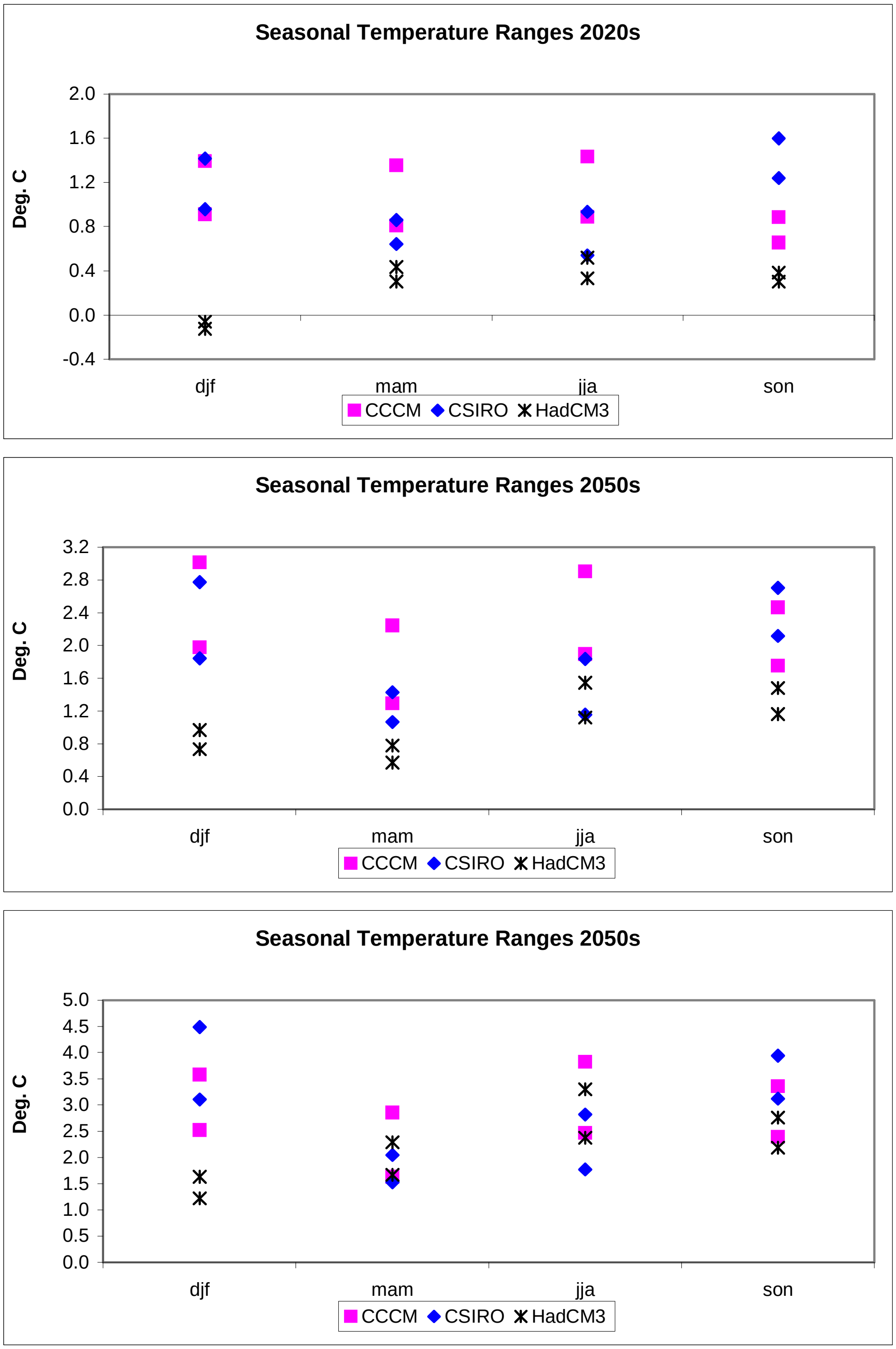
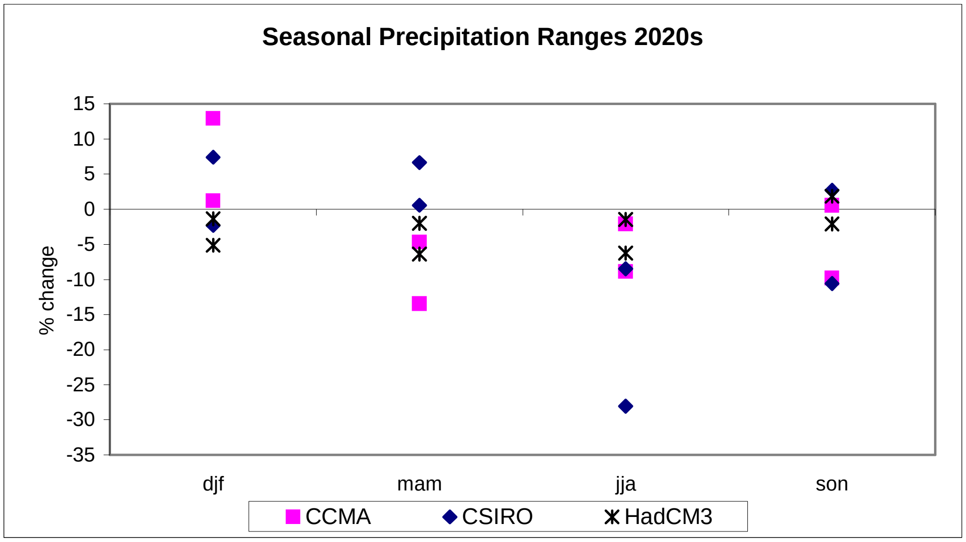


Figure 5. Seasonal temperature ranges for stations showing the smallest and greatest changes for the A2 emissions scenario

the CCCM GCM is associated with the largest amount of seasonal warming across the three time periods. The HadCM3 suggests slight cooling during the winter period for the 2020s, largely inconsistent with the other two GCMs, both of which indicate warming during this period. The three models also suggest a difference in the seasons likely to experience the greatest warming.

By the 2050s, all models indicate warming for all seasons. The between stations range is greatest for the CCMA GCM and smallest for the HadCM3 GCM. While the models are all consistent in predicting an increase in temperatures for all seasons, the range between the ‘warmest’ stations from both the HadCM3 and CCMA model suggest a difference of almost 2^{o}C in the winter season. This range is further enhanced by the 2080s, when the ‘warmest’ stations from the ‘warmest’ and ‘coolest’ GCMs suggest a difference of almost 3^{o}C. These differences largely arise due to different GCM model climate sensitivities and therefore, equilibrium temperatures under a doubling of the pre-1990 atmospheric CO_2 concentrations.

The stations showing the largest percent change and the smallest percent change in precipitation for the different GCMs are illustrated in Figure 6 for each of the three time periods and each season for the A2 emissions scenario. The range between these stations varies for



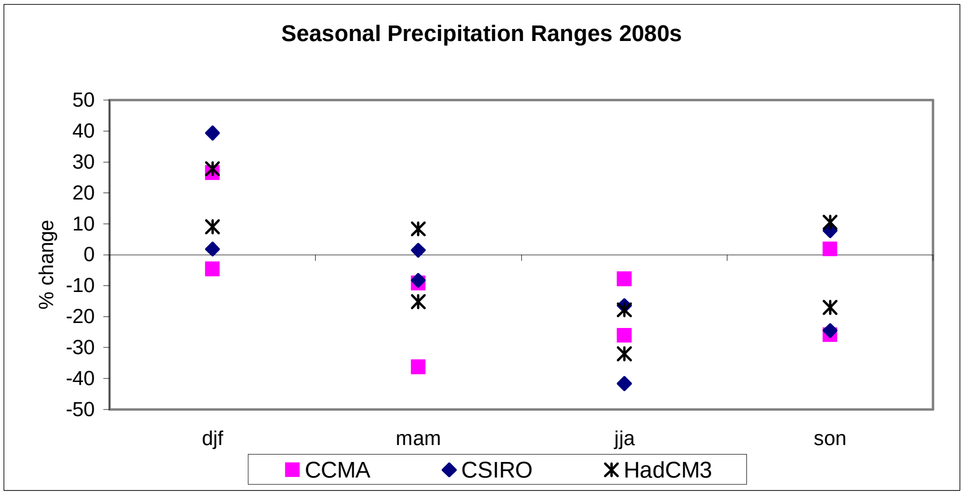


Figure 6. Seasonal precipitation ranges for stations showing the smallest and greatest changes for the A2 emissions scenario

each of the GCMs, with larger percentage and positive increases being demonstrated by the CCMA GCM, while the downscaled data from the CSIRO GCM suggests that some stations will increase while others will experience a decrease in winter precipitation by the 2020s. The HadCM3 based data indicate that all stations will experience a slight decrease in winter precipitation for this period. The summer months are the only period in which all models agree that there will be a decrease in receipts, but again the changes vary between models. A clearer seasonal picture emerges for the winter and summer periods by the 2050s, with all models again suggesting an increase in winter and a decrease in summer, but again the ranges between the 'driest' stations and 'wettest' stations and models are large. Similar results are found for the 2080s. Again, these results illustrate the large seasonal and spatial ranges and that can occur, even over an area the size of Ireland. Differences in the GCM model ranges demonstrate the importance of using a number of GCMs when conducting impacts analysis due to the various uncertainties that cannot be accounted for when employing just one GCM.

3. Climate Change and Irish Agriculture

3.1 Crops and Crop Yield

Using a set of monthly scenarios from only one GCM to drive crop yield models Holden and Brereton (2003) suggested the following impacts:

1. Major changes in the crops grown and their performance can be expected but there will be no catastrophic effects
2. The distribution of land use will alter. Livestock production will probably dominate more to the west and arable production will dominate east of the Shannon.
3. Maize will become a major crop.
4. Soybean may become a marginal specialist crop.
5. Planning for irrigation is needed to ensure that water costs are acceptable and summer surface and ground water resources are not over used.

3.2 Farm Management Issues

Modelling crop yield changes can be considered as representing only a preliminary assessment of how Irish agriculture will be impacted by climate change.

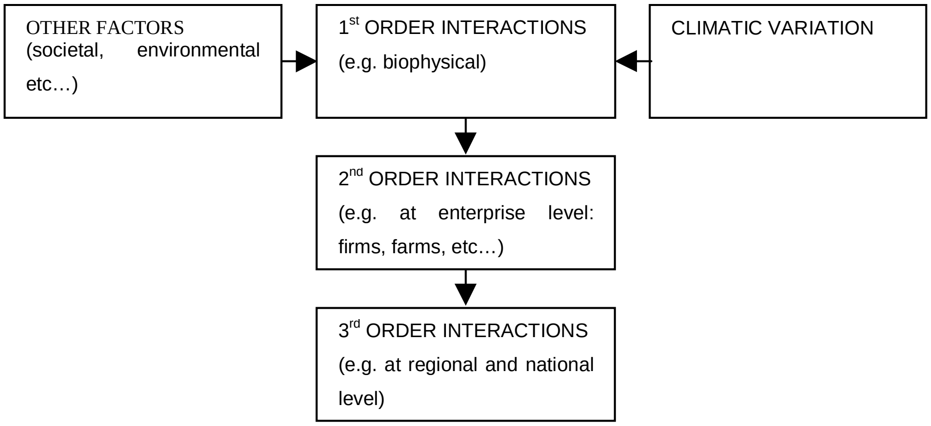


Figure 7. Approaches to assessing climate change – agriculture interactions

Adaptation measures also need to be considered. To address this a second phase of analysis was undertaken using daily resolution climate scenarios and multiple gcms as detailed above. Holden and Brereton then used this to examine 2nd order interations (Figure 7).

Conclusions

The main conclusions emerging from this part of the work can now be combined with the crop yield modelling outputs to produce the following overall conclusions:

- In eastern parts of Ireland, water stress in grass, barley, potato and to a lesser extent maize will occur with a much increased frequency by mid and later decades of the present century. Summer soil moisture deficits will be problematical for dairying, and milk yields can be expected to fall significantly during the summer months. Economic losses from this may be partially compensated by reductions in fertiliser inputs. Late summer feed deficits may occur and this may require supplementation. In particularly dry summers, cattle may require to be housed for a period.
- In the Midlands less soil moisture stresses are apparent in summer and good yields of grass, barley and maize can be expected. Later in the century, soybean can be expected to start displacing maize. The potential for reduced fertiliser inputs will be greater in areas of poorly drained soils.
- In western parts of Connaght and Ulster cool temperatures and relatively wet conditions will result in lower grass, maize and soybean yields than further east. Barley and potato yields will hold up well as will dairying.
- For many Irish farmers the key to adapting to climate change will centre either on maximising outputs or minimising inputs. Over most of the country a major consequence of climate change will be a need for significantly less nitrogen application

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