SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	July 2009 - December 2009
Project Title:	Changes in the North Atlantic Climate and Impacts for Ireland
Computer Project Account:	spiessti
Principal Investigator(s):	Dr. Shiyu Wang
Affiliation:	Met Eireann
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………………..…… ……………………………………………………………..……
Start date of the project:	January, 2008
Expected end date:	December, 2009

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)			50000	
Data storage capacity	(Gbytes)				

Summary of project objectives
(10 lines max)

The purpose of this study to develop a regional state-of-the-art atmosphere-ocean couple model system. The regional climate model used in this study is Rossby Center model RCA3 and the regional ocean model is NEMO. All the models will be coupled by OASIS3 coupler program. Our primary scientific goal is to use this coupled model to understand the physical processes affecting the extreme events over Ireland.

Summary of problems encountered (if any)
(20 lines max)

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Summary of results of the current year (from July of previous year to June of current year)
This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

1. The development of the coupled atmosphere-ocean regional model RCA_NEMO

1.1 Introduction

For the next two decades, a warming of about 0.2° Celsius per decade is projected for a range of SRES emissions scenarios. After that time-frame, temperature projections increasingly depend on specific emissions scenarios. The temperature could increase 1.8-4.0°C by the end of 21st century (IPCC, 2007). Since the equilibrium climate sensitivity is a measure of the climate system, the response to sustained radiative forcing and feedback can amplify or dampen the response to a given forcing. Direct emission of water vapour makes a negligible contribution to radiative forcing, but the increased temperature represents a positive feedback. According to the past IPCC report, water vapour represents the largest positive feedback affecting the equilibrium climate sensitivity. As the increased temperatures will lead to greater amounts of water vapour in the atmosphere and an accelerated global water cycle, it can be expected that Ireland will be at a greater risk of river or coastal flooding.

In Ireland, flooding is associated mainly with heavy rainfall, which can lead to enhanced river-flow and over-topping of river banks. However, coastal flooding events are often more serious, particularly those associated with elevated sea levels and storm surges (Wang, 2008). The effects may be enhanced locally by the coastal topography. Due to the effect of the Atlantic Ocean and the Gulf Stream, the ocean plays an important role in the Irish climate and it is essential to take into account the combined effects of the ocean and atmosphere.

Over the past few decades, there has been better understanding of physical processes, and more precise finite difference methods for solving the primitive equation models. This state-of-the-art knowledge has been integrated into climate model developments. Coupled atmosphere-ocean general circulation models (CGCMs) are becoming increasingly important tools in climate change science. However, due to their coarse resolution, CGCMs cannot capture detailed local information over Ireland, particularly in coastal regions. The more detailed descriptions of coastlines and land elevations available in regional climate models (RCMs) enable them to provide local detail not available from the CGCMs.

RCMs usually include a sophisticated land surface scheme. However, oceanic information provided by the CGCMs in the form of sea surface temperature fields is passively handled by the regional model, and very little effort has been made to treat precisely the flux from the sea surface in RCMs. The atmosphere and ocean are not independent: they are closely interrelated through fluxes of heat and moisture at the sea surface. The interaction between the atmosphere and ocean needs to be included in RCMs in a more sophisticated way, especially to properly reproduce the climate over Ireland.

Processes at the ocean-atmosphere interface, which couple the different systems and affects atmospheric and ocean circulation, are still poorly understood. In particular, considerable uncertainty exists regarding the role of storm surges, or wave-related processes, that are expected to significantly affect the coupling fluxes of momentum, heat and moisture, all of which play an important role in coastal flooding. A coupled regional atmosphere-ocean model system will enable us to shed more light on these issues. Another goal of the coupled atmosphere-ocean models is to probe the impact of anthropogenic activities on climate change over Ireland.

In this study, a high-resolution ocean model and atmospheric model are coupled. The performance of the coupled model version is verified against the atmosphere-only version. To demonstrate the reliability of the coupled model, we performed 31-year integrations driven by ERA40 reanalysis data (Uppala, 2005). The reproducibility of the present climate was investigated by comparing the calculated results with different observational data to evaluate the performance of the coupled model.

1.2 Model description

1.2.1 Atmosphere Model

The atmospheric component of the coupled model is the Rossby Centre Regional Atmospheric Model (RCA) developed from the High Resolution Limited Area Model (HIRLAM). Briefly, the RCA model is the climate version of the operational model HIRLAM. The RCA is a primitive equation hydrostatic model using a terrain-following hybrid vertical coordinate. Most HIRLAM parameterisations have been retained in RCA. Some physical parameterisations have been changed for newer schemes (Räisänen, 2004). In addition, RCA hosts a new land surface scheme and some hydrological processes are included (Rummukainen et al., 2001; Jones, 2001), i.e. soil moisture transfer includes Darcian flow and runoff is routed down the soil column as in the hydrological HBV model. The land surface-soil scheme has two prognostic layers for temperature and soil moisture. This model has been widely used for climate change studies over Ireland and for simulating the European climate in the ENSEMBLES project (2004-2009), using different resolutions.

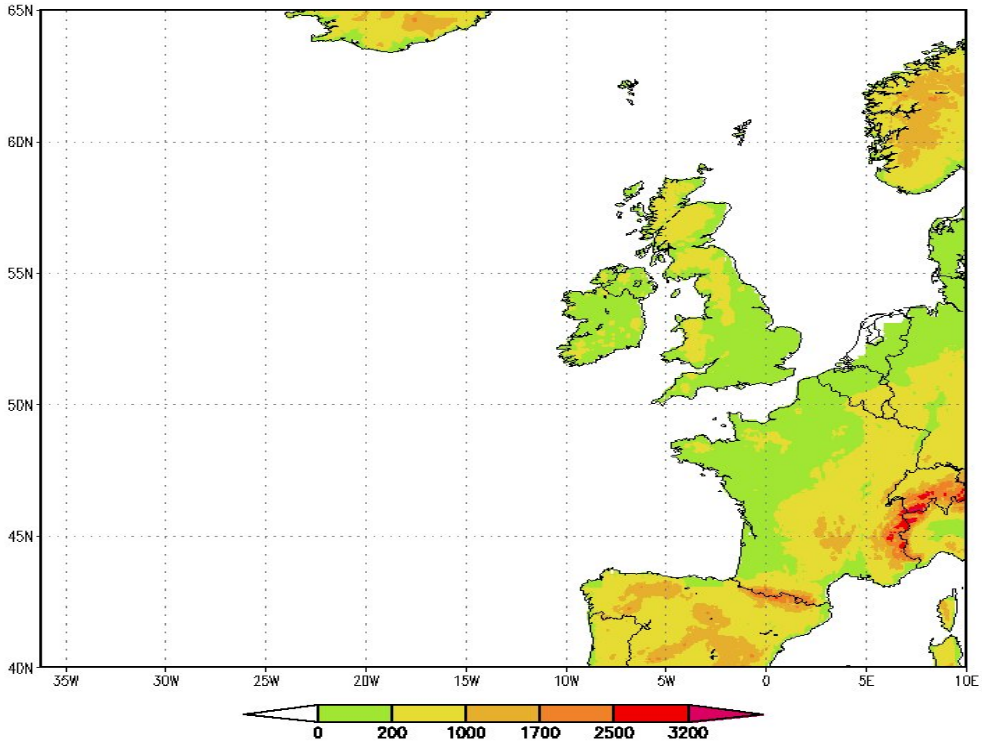


Figure 1 Orography in the model domain (Unit: metres)

In this study, the RCA model domain has been set up with a 0.25 degree spherical, non-rotated latitude/longitude grid (Fig.1). The choice of the area used to perform the downscaling is guided by a desire to cover all Irish coastal areas. Since the ocean plays an important role in the atmosphere-ocean interaction, the model domain is chosen to cover a broad area of the North Atlantic.

1.2.2 Ocean Model

The oceanic part of the coupled model is the Nucleus for European Modelling of the Ocean (NEMO) model, a primitive equation model adapted to regional and global ocean circulation problems. The NEMO model solves the incompressible and hydrostatic primitive equations with free surface horizontal curvilinear coordinates and utilizes a stretched Z-coordinate, with partial steps that enhance the vertical levels near the sea surface (Madec, 2008). In addition, the turbulent fluxes (which represent the effect of small scale processes on the large scales) are expressed in terms of large-scale features, and the density variations are neglected except in their contribution to the buoyancy force. A sophisticated algorithm scheme, combing radiation and relaxation, is used along the open boundaries in order to allow for stable, long-term integrations, together with a flow-adaptive nudging term for relaxation toward the prescribed lateral boundary conditions. That is, the nudging is stronger (time scale of 1 day) if the flow is inward and weaker (time scale of 1 year) for outflow (Marchesiello et al., 2001).

On the base of global NEMO model, a regional ocean model is adapted for our study. The model domain is the same as the atmosphere model, which is configured at 0.25° resolution covering large part of North-east Atlantic Ocean. Considering the different factors that can affect the simulation results, several sensitivity experiments are designed to test this regional ocean model, such as different forcing fields, effect of open boundary conditions, initial fields and the vertical levels. Climate monthly mean wind stress and heating fields are used to drive the model. Such datasets are appropriate for studying an equilibrium structure of ocean currents (Marchesiello et al. 2003; Di Lorenzo 2003; Di Lorenzo et al., 2005). The preliminary simulations show that the regional NEMO model is capable of reproducing the basic oceanic features; a 42-level z-coordinate is chosen for the coupled model .The initial fields and lateral boundary forcing fields are taken from Levitus data (World Ocean Atlas (1998)) (Antonov, 1998; Boyer, 1998).

1.2.3 OASIS3 coupler

The Ocean Atmosphere Sea Ice Soil Simulation Software (OASIS3) coupler, developed by the Project for Integrated Earth System Modelling (PRISM), is software that allows synchronized exchanges of coupling information between numerical codes representing different components of the climate system (Valcke, 2006).

For the coupling process, OASIS3 acts as a separate mono-process executable, whose main function is to interpolate the coupling fields exchanged between the component models. OASIS3 supports 2D coupling fields only. The Spherical Coordinate Re-mapping and Interpolation Package (SCRIP) provided by Los Alamos National Laboratory is integrated in the OASIS3 coupler (Jones, 2001). SCRIP supports four re-mapping options: conservative remapping, bilinear interpolation, bicubic interpolation and distance-weighted averaging, of which bilinear and bicubic interpolations are suitable for logically-rectangular grids. In this study, since the model domain only extends to mid-northern latitudes, and the grids of the atmosphere and ocean models are only slightly different, the bicubic method is used for the interpolations.

1.2.4 Coupling Procedures

To build up a coupled modelling system, the OASIS3 coupler bridges the atmosphere model RCA and ocean model NEMO (Figure 2). This coupler works in a sequential fashion which synchronous coupling of the different model components at 3 hours interval. The interfacing boundary layer between RCA and NEMO is based on either RCA's boundary layer physics package or on the bulk formula that is implemented in NEMO. The former calculates forcing fields necessary to drive NEMO. Surface fluxes of heat and momentum from the atmosphere are transferred to the ocean, and NEMO then forces RCA at the lower boundary by providing the SST. Absorbed solar radiation on the open ocean surface penetrates through the first three layers of the ocean according to the formula of Paulson and Simpson (1977). The absorbed insolation affects both the mean and the vertical gradients of potential enthalpy in the ocean.

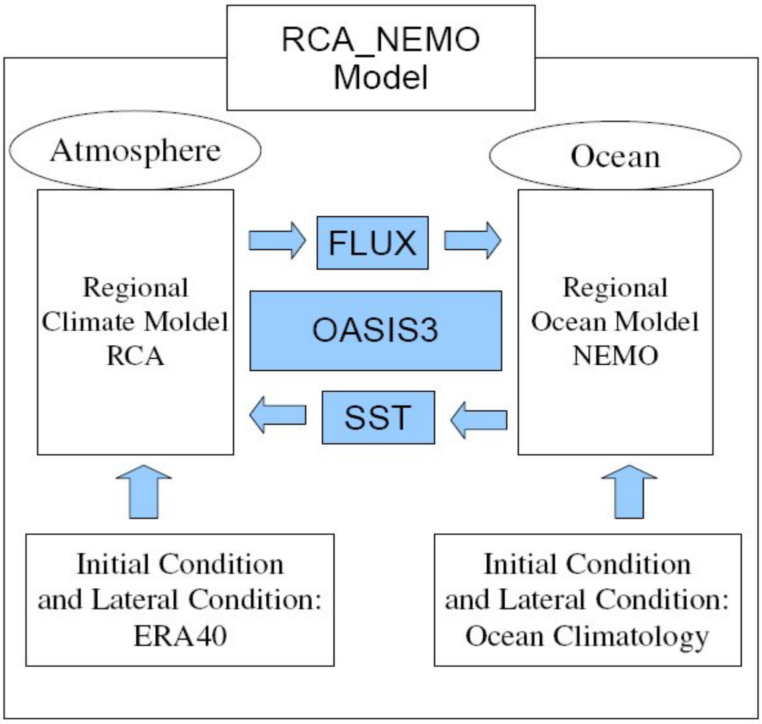


Figure 2 Schematic description of the RCA_NEMO Model; initialization and lateral forcing of the RCA are obtained from ERA40 reanalysis data. Initial and boundary conditions for NEMO are from Levitus climatological mean temperature and salinity.

Both atmospheric and ocean models conventionally assume that atmospheric wind stress imposed on the sea surface is a function of atmospheric wind only. This is often justified, owing to the fact that ocean current speed is typically small compared to the wind speed by an order of magnitude. Difficulties in obtaining direct wind stress data cause, in many cases, the wind stress to be computed from bulk formulas that estimate turbulent fluxes on the basis of standard meteorological data. Large and Pond (1981) developed a simple algorithm consisting of a bulk formula for calculating the drag coefficient using only the wind velocity which has been used in this study:

$C_d=1.2\times10^{-3}$ $\quad 4<V<11 ms^{-1}$
$C_d=(0.49+0.065V)\times10^{-3}$ $\quad 11<V\ ms^{-1}$

where V is the absolute value of the wind velocity, and C_d is the drag coefficient. This algorithm has also been used in many studies such as Dorman et al. (2000), Samelson et al. (2002), and Koracin et al. (2004).

This coupled model has several distinctive features. It is truly synchronously coupled, with joint physical processes every three hours; the non-linear free ocean surface allows for direct interactions between the ocean and atmosphere without requiring surface flux corrections or ocean restoring.

1.2.5 Experimental Design

In this study, two simulations were performed for the period 1960 to 1990: an atmosphere-ocean coupled run and a non-coupled atmospheric run. For the atmospheric model, both simulations were driven by ERA40 data from the European Centre for Medium-Range Weather Forecasts (ECMWF) at the lateral boundary, while the prescribed SST from ERA40 is only used for the atmospheric run. In the coupled run, the initialization and lateral boundary conditions of the NEMO model are provided by Levitus data from the World Ocean Atlas (1998). The first year of simulation is discarded to allow the coupled model to spin up.

1.3. Results

1.3.1 Mean Sea Level Pressure (PMSL)

The variation of surface temperature has an association with the atmospheric moisture. Its intensity will affect the frequency of cyclones with possible consequences for the Irish climate, particularly for extreme precipitation and storm surge. Semmler's (2008) study shows that the increased SST will cause an increase in the frequency of very intense cyclones with maximum wind speeds of more than 30m/s. Generally, cyclone activity is strongly associated with mean sea-level pressure (PMSL). It is thus useful to evaluate the impact of this two-way interaction process on PMSL.

Figure 3 depicts the 30-year (1961-1990) averaged monthly mean PMSL for January. For convenience, the ERA40 reanalysis data is used. In the regional climate simulation, the lateral boundary forcing of an RCM largely determines the simulated surface temperature. Since ERA40 data are also used to drive RCA3 in this study, systematic errors of PMSL fields in the driving fields also largely determine the errors in the RCM temperature (Noguer, 1998). It should be noted that, although reanalysis data have the advantage over observational data of being spatially complete, some systematic errors exist in the reanalysis data. Reid (2001) found that the local errors are relatively small over the European region.

In January (Figure 3), ERA40 data shows a low pressure system in the region of Iceland and high pressure system over the Iberian peninsula. The stronger Azores high in the ERA40 data even reaches the north of the Mediterranean. These broad features have been reproduced by both the uncoupled run and coupled run. There is no significant difference between these two simulations. The bias is less than 1hPa. This confirms previous findings that the large-scale character of the pressure field in an RCM is largely determined by the driving GCM data (e.g. Noguer et al. 1998).

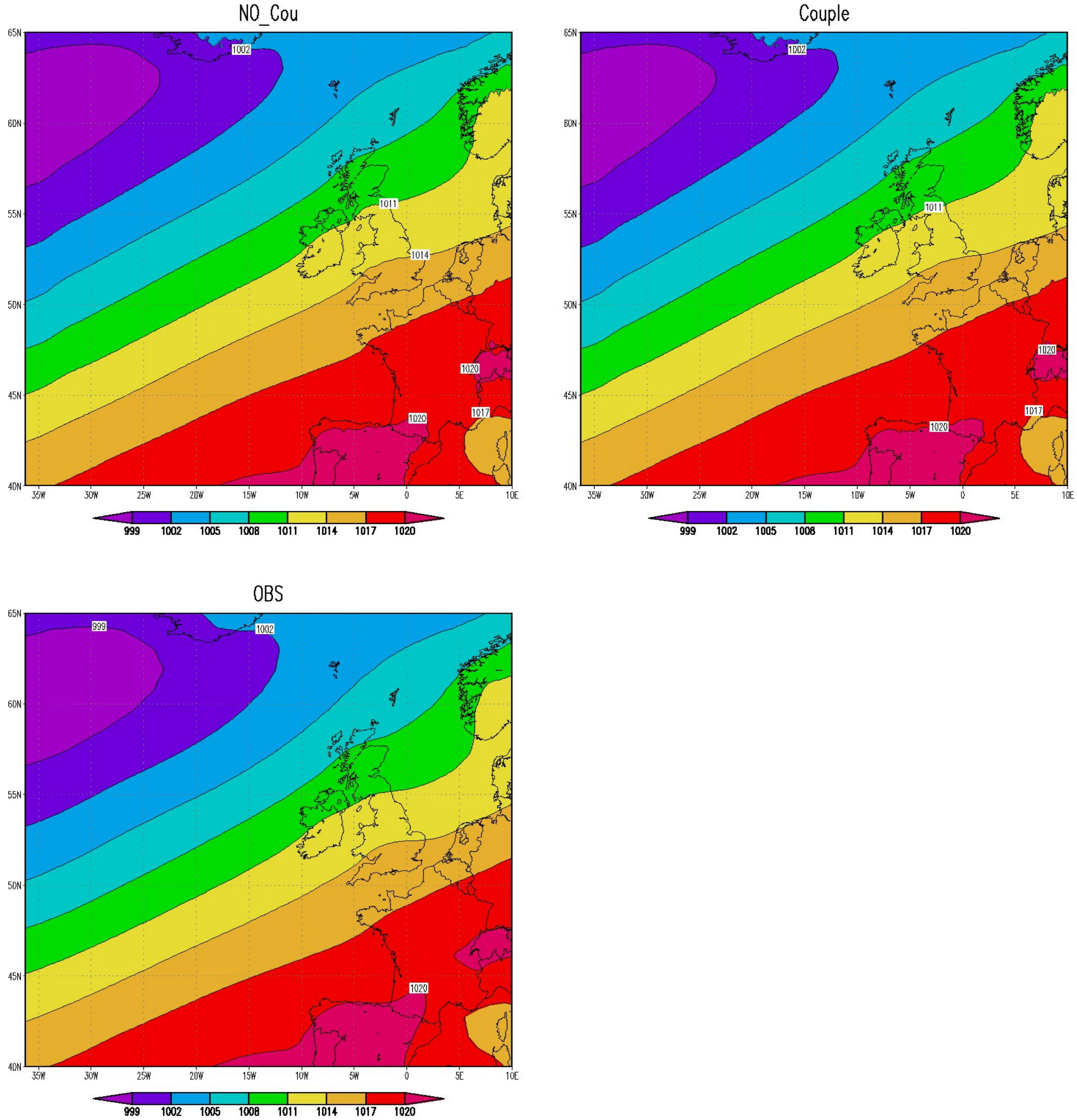


Figure 3 Average PMSL fields(1961-1990) for January (a) non-coupled run,(b) coupled run, (c) ERA40

In April (Figure 4), both simulations can capture the Iceland low fairly well; however, there is an obvious difference for the high pressure system simulation, particularly in the uncoupled run: the simulated pressure gradient is much weaker compared to ERA40 data and to the coupled run. This indicates a weaker advection of moist air from the Eastern Atlantic Ocean to Ireland, which will bring less warm and humid air. Figure 5 shows the 2 meter relative humidity (Q2m) for the simulations, the observed field (based on observations) and the difference between the uncoupled and coupled run. The observed Q2m is taken from the Climatic Research Unit (CRU) data. This climatology data was interpolated from a data set of station means for the period centered on 1961 to 1990 at 10 minutes resolution (New, 2002). From the observations, the whole of Ireland is covered by moist air (Q2m >85%), whilst the simulations give relative dry condition, especially in the uncoupled run, which is consistent with the distribution of PMSL. The differences between the coupled and uncoupled runs are more than 2% in the Central Plain of Ireland. The Student-t test result shows that the difference is significant over most of Ireland at the 95% level (Figure not shown).

Results for July and October are similar to January (Figures not shown): there are no pronounced differences. However, contrasting with April, the coupled run has a lower Q2m distribution, particularly in July, where the difference is much more pronounced. In addition, the difference is significantly different at the 95% level, according to the Student-t test.

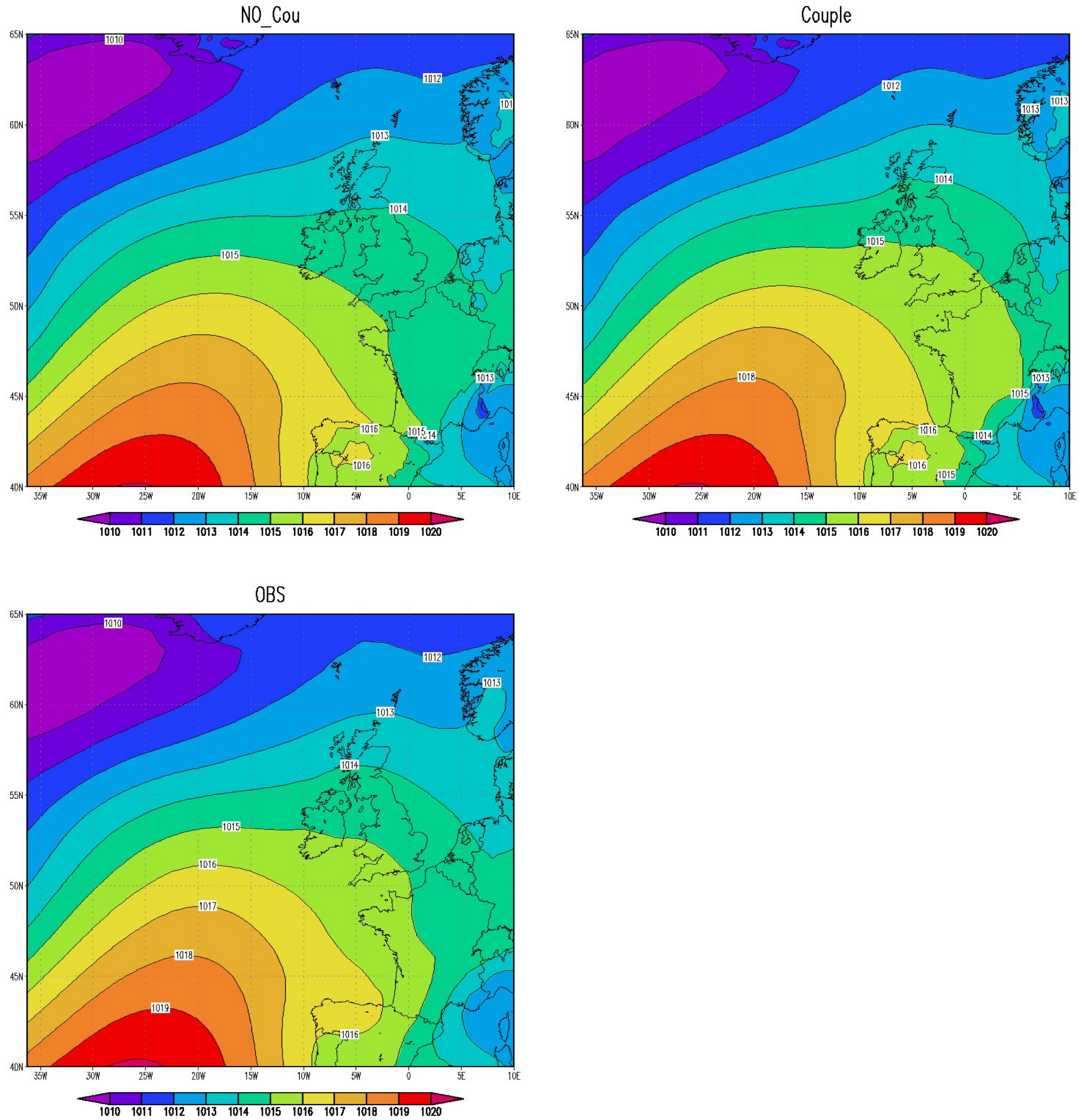


Figure 4 Average PMSL fields (1961-1990) for April (a) non-coupled run,(b) coupled run, (c) ERA40

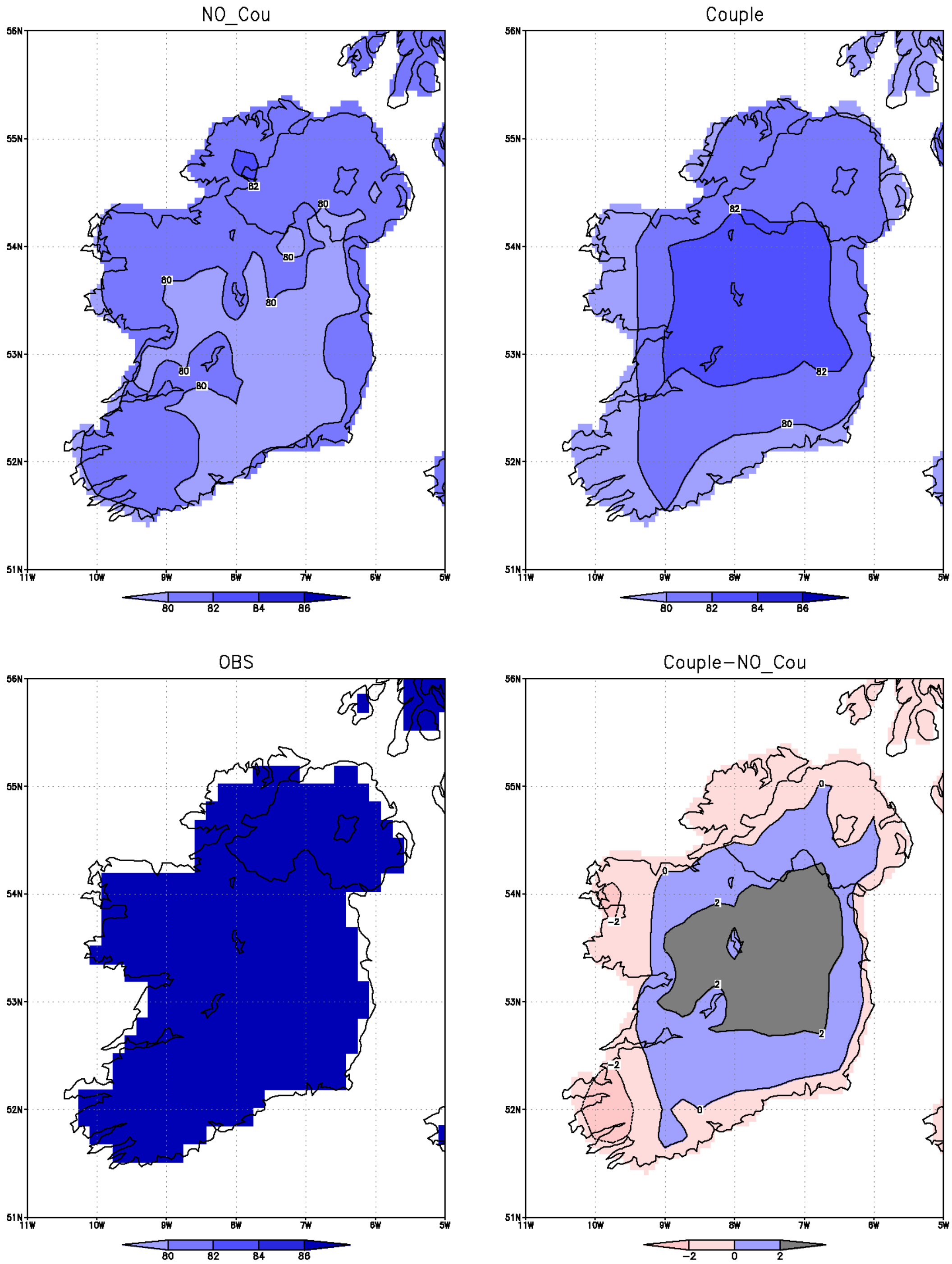


Figure 5 Average Q2m (%) fields (1961-1990) for April (a) non-coupled run, (b) coupled run, (c) CRU data (d) difference between coupled and uncoupled

1.3.2 Precipitation

In this study, the UKCIP (UK Climate Impacts Programme) data is used for verifying the model's precipitation. This observational data is calculated using the Irish meteorological synoptic data with the UKCIP interpolation package. This analysis process uses geographical information system (GIS) capabilities to combine multiple regression with inverse-distance weighted interpolation. Geographic and topographic factors such as terrain height and shape, and urban and coastal effects are incorporated either through normalization with regard to the 1961–1990 average climate, or as independent variables in the regression. Precipitation is then incorporated through the spatial interpolation of regression residuals (Perry, 2005). It's horizontal resolution is 0.05°, about 5km. The monthly mean values are calculated for the period 1961 to 1990.

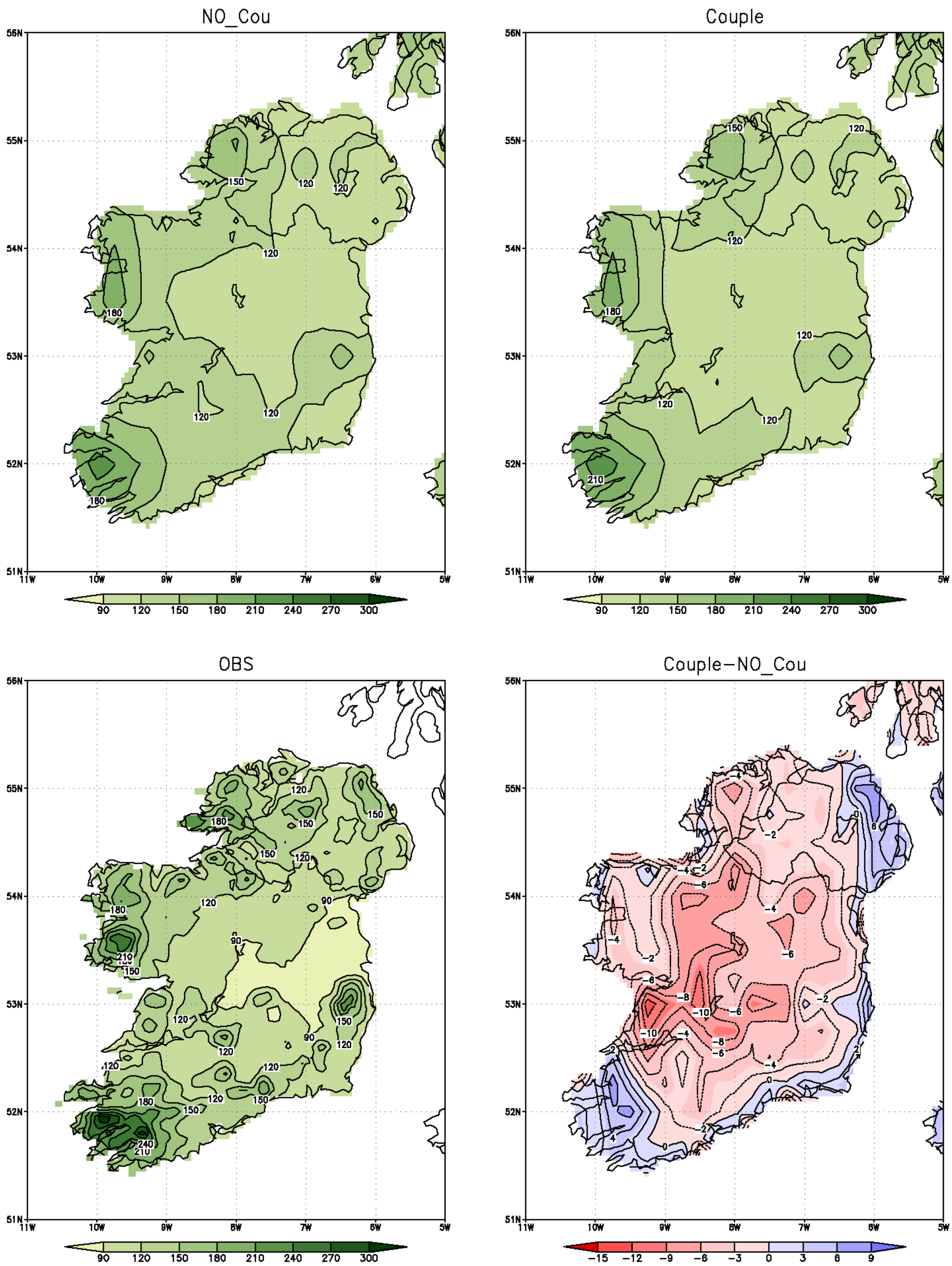


Figure 6 Average precipitation fields (1961-1990) for January (a) non-coupled run, (b) coupled run, (c) observation, and (d) difference between coupled and uncoupled runs.

Due to the impact of the Gulf Stream, the strong westerly flow brings warm air from the Atlantic Ocean to the west coast of Ireland. This results in a distinct contrast between the coastal region and inland region, producing more precipitation along the west coast mountainous region and less precipitation in the inland region. In January (Figure 6), both simulations can reproduce these broad features. However, the precipitation amount in the high precipitation region is slightly lower compared to the observation data. The current simulation is run at 25km, which is still relatively coarse to resolve the convective systems. This may be one of the reasons for lower precipitation. By comparison, in the C4I (Community Climate Change Consortium for Ireland) simulation, which ran the same model at much higher solution (about 13km), the simulated monthly precipitation has much better agreement with the observations, especially in the west coast region, which implies that high resolution can improve the simulation of precipitation. However, even in the high resolution simulation, the precipitation in the inland regions is still overestimated. Although both simulations have produced similar patterns, the coupled run more accurately reproduces the observed characteristics, which can be distinctly seen from the comparison between the uncoupled and coupled run. The difference between the coupled run and uncoupled run demonstrates that the coupled run has improved the simulation of precipitation in the west coast and inland regions i.e. increased precipitation in the west coast region and part of the east coast, and less precipitation in the inland region. The monthly mean precipitation in the coupled run is closer to the observations.

Extreme precipitation is another important factor in climate change. As mentioned in the introduction, floods caused by heavy precipitation in Ireland are damaging and costly in both economic and human terms. To investigate the impact of climate change on extreme precipitation, the model needs to reproduce realistically the extreme events of the present day. With respect to the precipitation in the contiguous United States, Karl and Knight (1998) found that the increase seen in the annual total rainfall was driven by an increase in the upper 10% of rainfall events, suggesting that the annual total rainfall and extreme precipitation are dependent. However, Christensen et al. (2003, 2004) find an increase of very high quantiles for the region of Central Europe, where mean precipitation decreases. Their researches show that there seems to be no simple relationship between the annual precipitation and extreme precipitation events in different regions. Both researches reveal the complexity of the extreme precipitation evaluation. However, their studies also indicate that the extreme events can make a contribution to the monthly precipitation increase.

To evaluate heavy precipitation events over Ireland, the number of wet days of each month is used as a simple index. In this study, a day is defined as a wet day if the daily precipitation amount exceeds 10mm. Figure 7 shows the average wet days (1961-1990) for January for (a) the non-coupled run, (b) the coupled run, (c) observations and (d) the difference between coupled and uncoupled runs. As for the monthly mean precipitation, the wet day number is generally overestimated in the uncoupled run. It is clear from the difference between the coupled run and uncoupled run that, except in the southwest region, the coupled run has slightly less wet days. As winter is climatologically the wettest season in Ireland due to the impact of the Gulf Stream and strong westerly flow, the improvement in the simulation of monthly mean precipitation and heavy precipitation events in January will provide more realistic results in the study of future climate change.

Reproduction of the precipitation in the warm season is also important for regional climate modelling. Kiely (1999) analyzed the observed precipitation over the past 50 years over Ireland. Based on eight rain gauge stations, the results show that there has been a trend towards increased rainfall and a strong variability since 1975. In the monthly mean precipitation, there are abrupt increases in March and October after 1975. Wang (2006) studied the spatial distribution of precipitation between 1961 and 2000. Using a high resolution regional climate model, it is found that there are two spatial patterns: in the west and north-west of Ireland, there is an increasing trend in the last 20 years of the 20^{th} century, while in the south and southeast, there is very strong variability.

In April (Figures 8 and 9), both the distributions of monthly mean precipitation and wet days show that the precipitation is overestimated over the whole of Ireland in the uncoupled run. Due to the relatively coarse resolution of the simulation (25km), the orography effect may not be represented by the model in full detail. Comparing the results of both models, the precipitation amount and wet days of the coupled run are almost always smaller than that of the uncoupled one, particularly in the Wicklow Mountains region, due to the realistic SST.

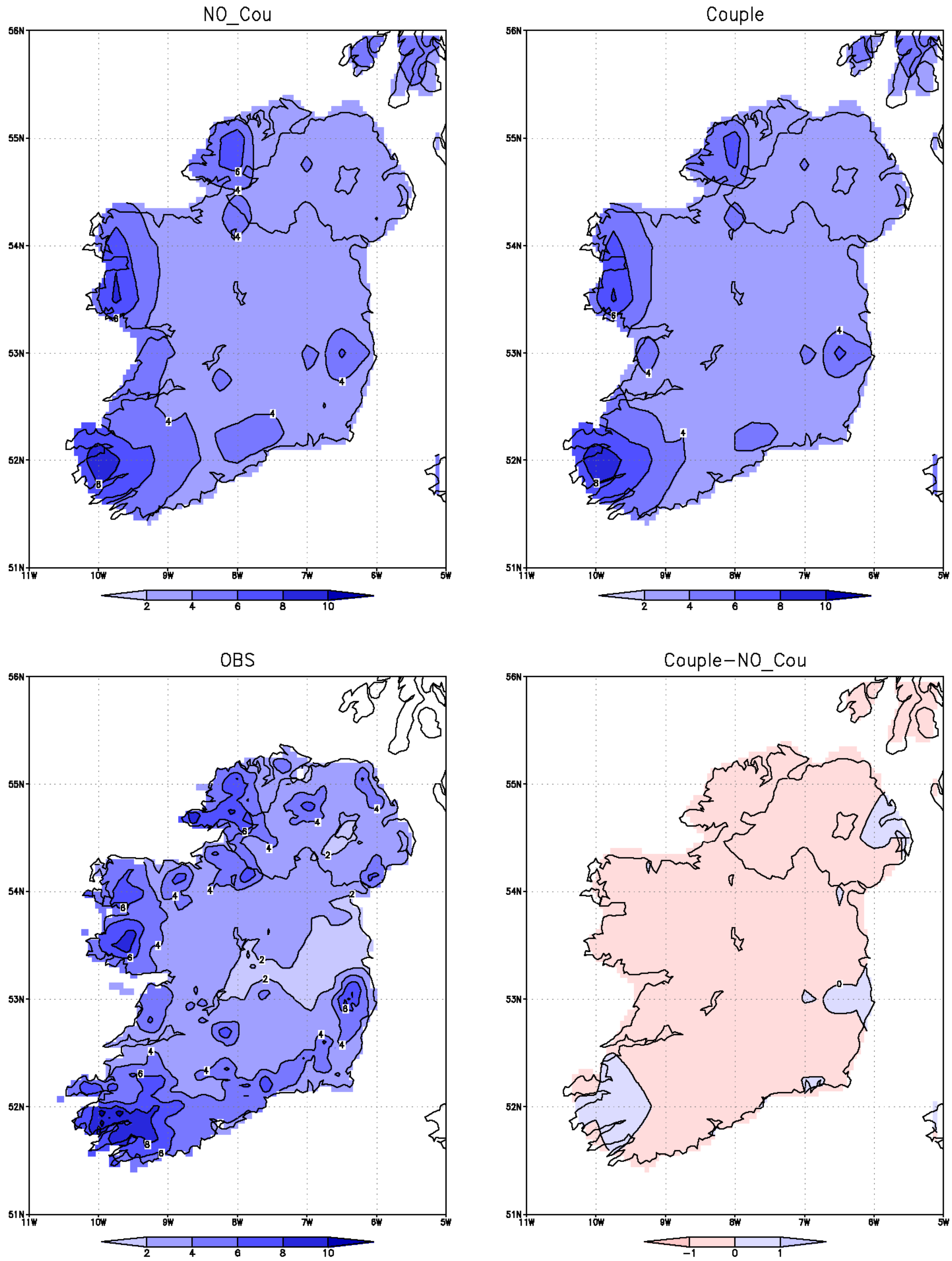


Figure 7 Average Wet days (1961-1990) for January (a) non-coupled run, (b) coupled run, (c) observation (d) difference between coupled and uncoupled

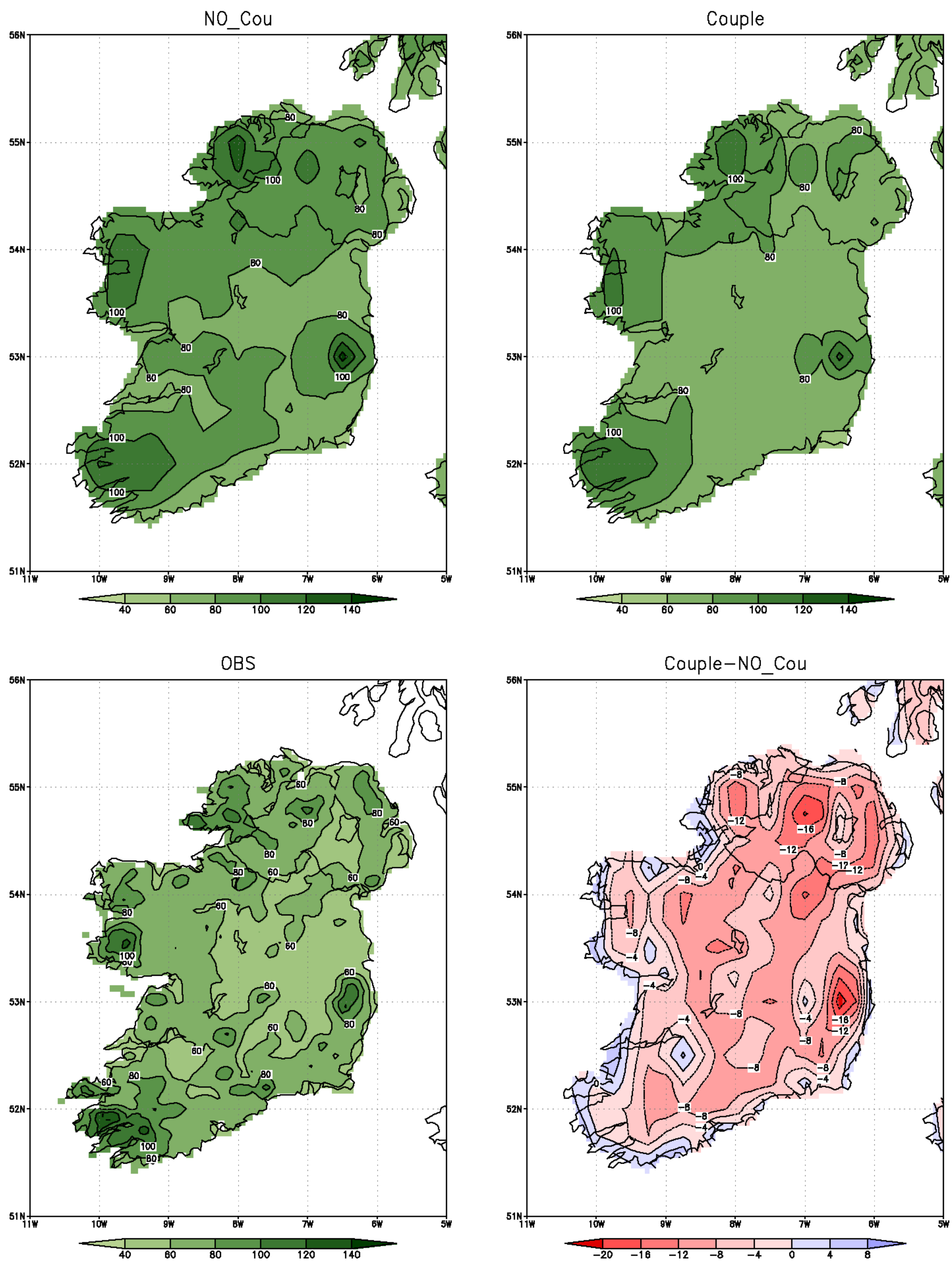


Figure 8 Average precipitation fields (1961-1990) for April (a) non-coupled run, (b) coupled run, (c) observation (d) difference between coupled and uncoupled runs

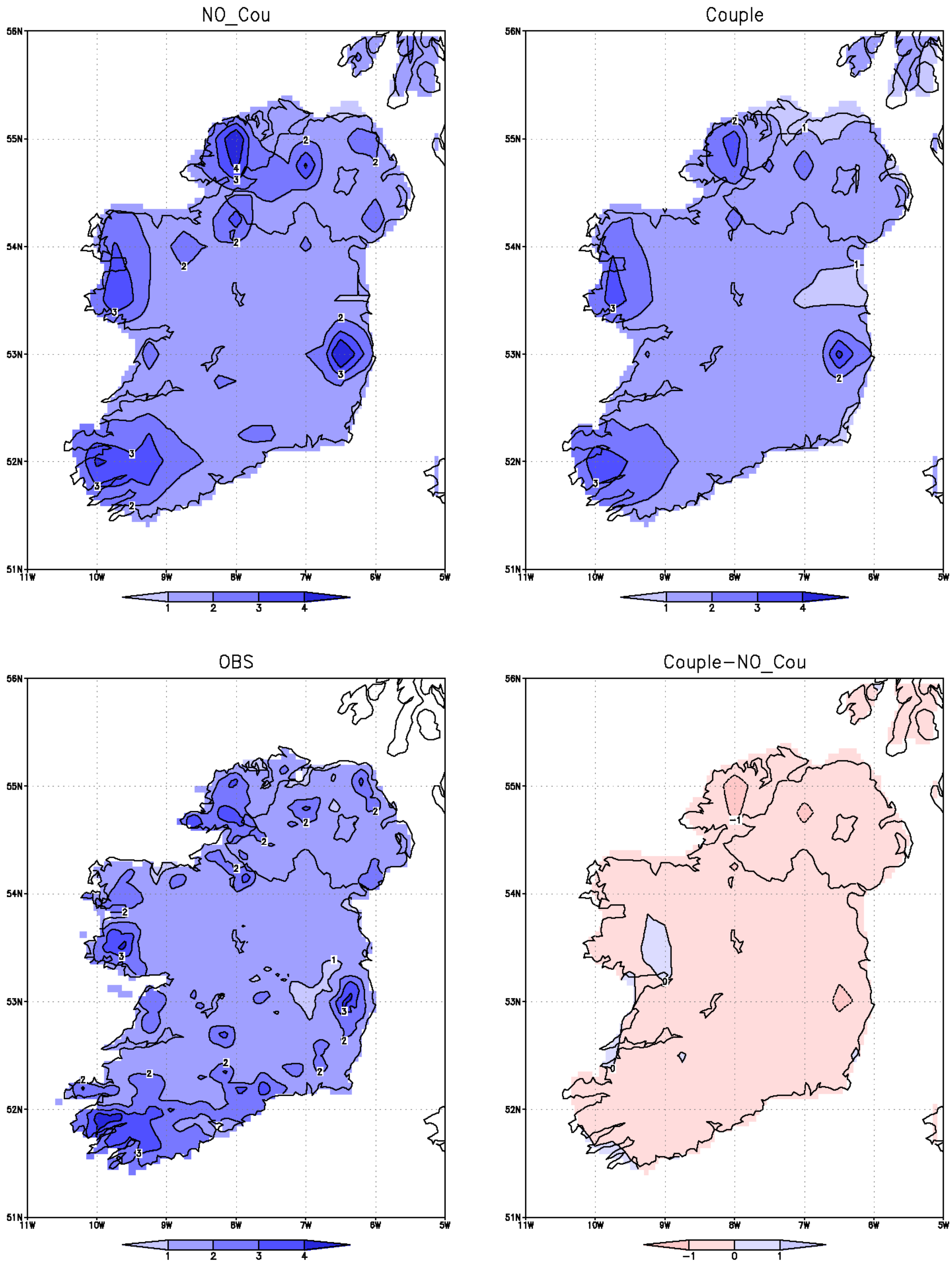
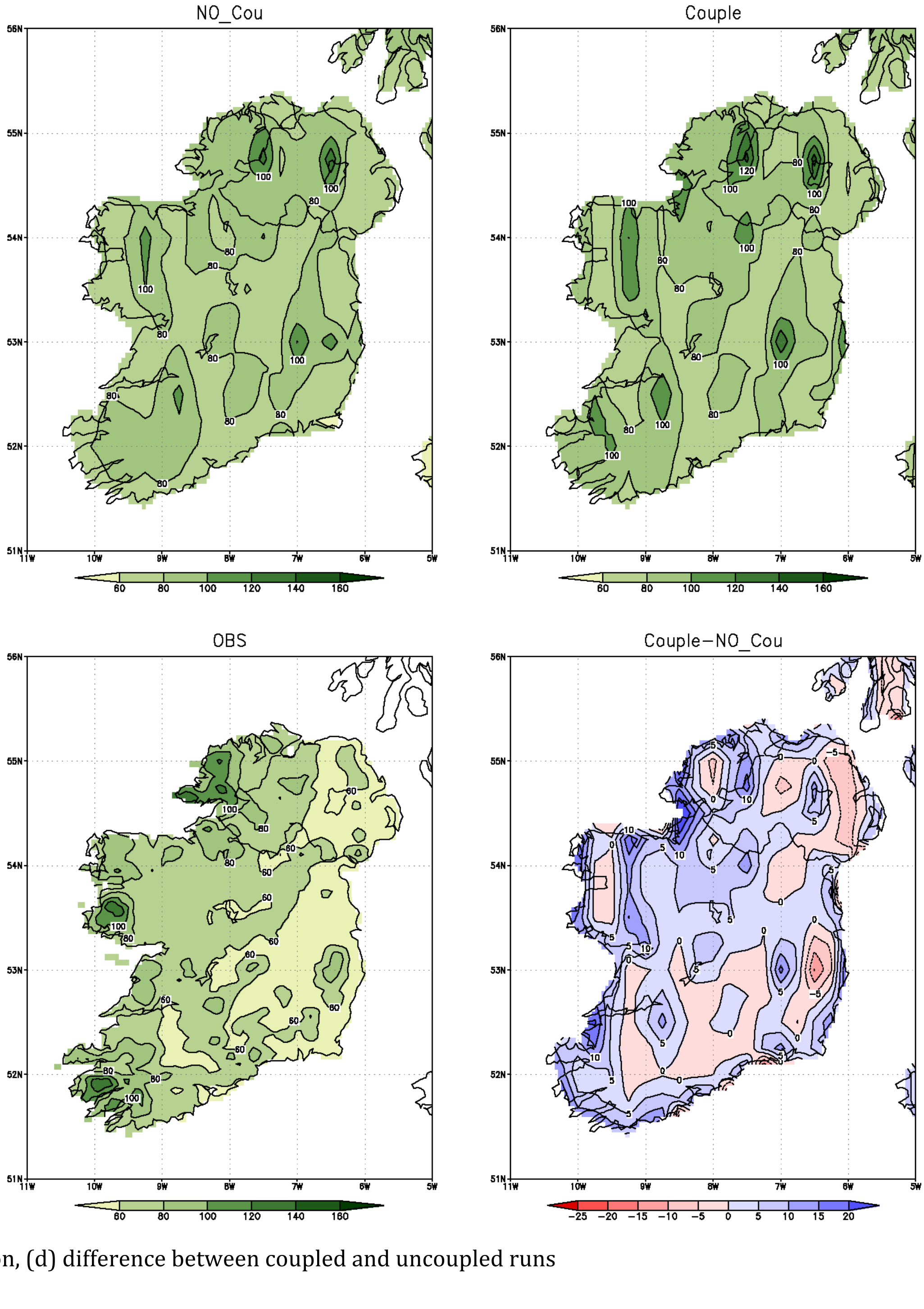


Figure 9 Average Wet days (1961-1990) for April (a) non-coupled run, (b) coupled run, (c) observation (d) difference between coupled and uncoupled runs

In July (Figure 10), the regional difference is relatively smaller in most of the country compared with the January and April results. Another distinct difference is that the precipitation amount has increased in the lowland region, which may be caused by the warmer SST in the summer. This distribution characteristic is also illustrated by the wet days distribution (Figure not shown).

In October (Figure 11), the coupled run shows similar improvements in the south of Ireland. However, the precipitation in the north of Ireland is slightly overestimated. The wet days distribution (figure not shown) also shows that there are slightly more wet days in the northeast region, which perhaps contributes to the enhanced precipitation.

Figure 10 Average precipitation fields (1961-1990) for July (a) non-coupled run, (b) coupled run, (c)



observation, (d) difference between coupled and uncoupled runs

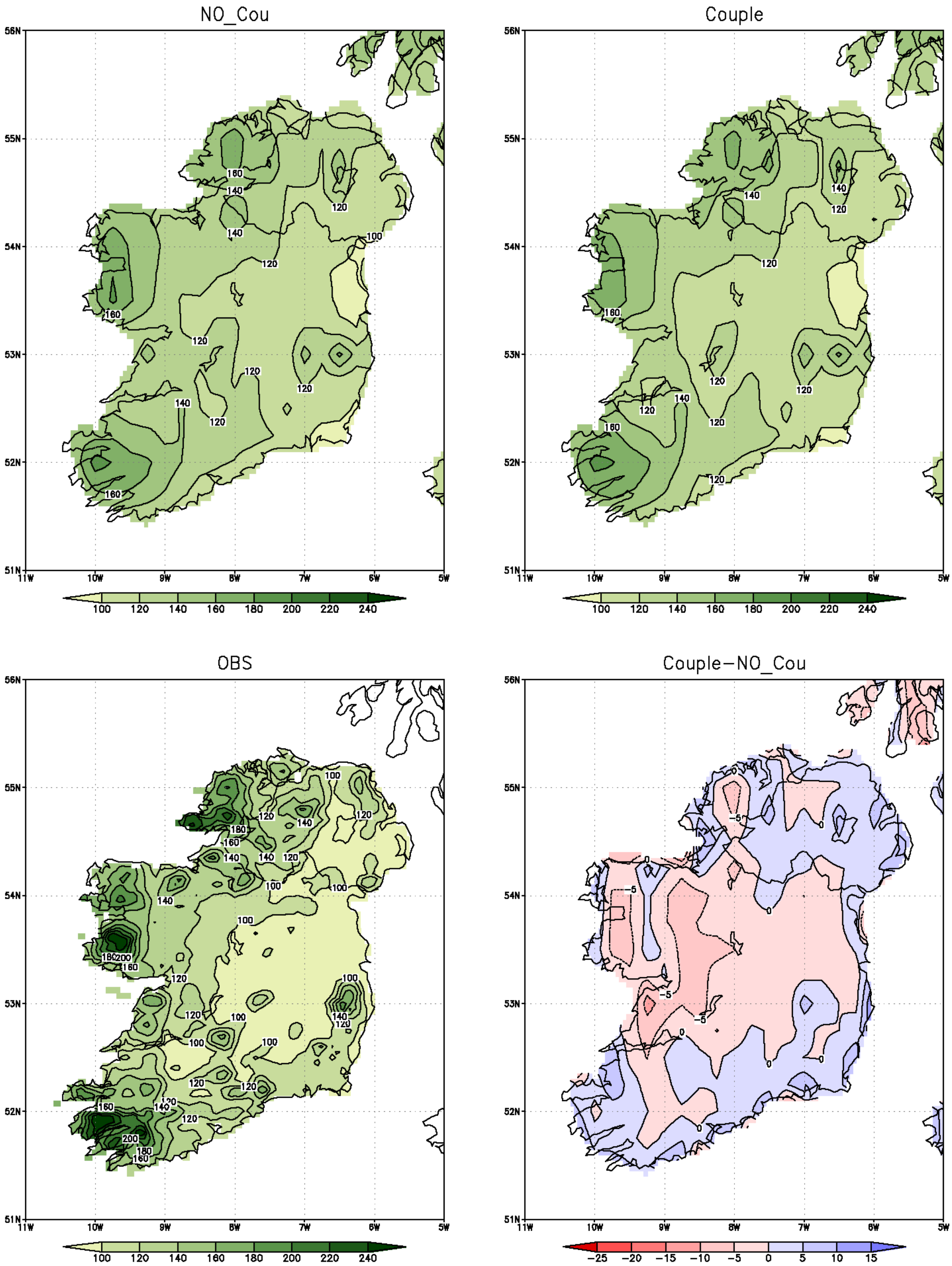


Figure 11 Average precipitation fields (1961-1990) for October (a) non-coupled run, (b) coupled run, (c) observation (d) difference between coupled and uncoupled runs

1.3.3 2m temperature

Temperature is one of the primary factors controlling growth of crops and forests. In Ireland, the annual mean temperature has a distinct north-northeast to south-southwest gradient and varies from 9.0°C in parts of the north-east to over 10.6°C in the extreme southwest (Keane, 2004). The yearly fluctuations are relatively small. It should be noted that there is also a generally warming trend in recent decades.

Figure 12 depicts the monthly mean 2m temperature (T2m) for January. Due to the impact of the Gulf Stream and Atlantic Ocean, Ireland enjoys a moderate climate. The spatial pattern of surface temperature is comparatively simple. As for precipitation, the observed T2m from UKCIP data is used to quantitatively investigate the model's reproducability. As stated above, the observations show that T2m has a small gradient, which slowly increases from 4°C to 5°C. As illustrated in Figure 12, both simulations have reproduced the basic spatial pattern; however, the T2m has been overestimated in most regions, particularly in the coupled run. The land-sea contrast is more pronounced in the coupled run. The difference between the coupled run and uncoupled run demonstrates that the bias in the coast region exceeds 1 degree, except in the lowland region where the temperature is slightly cooler. It is reasonable to assume that the differences between the SST fields for the coupled and uncoupled runs is the source of the 2m surface temperature difference.

Figure 13 illustrates the distribution of monthly mean T2m for April. In the uncoupled run, simulated T2m is still overestimated as in January, especially in the south of Ireland. However, the bias between the coupled run and uncoupled run shows that simulated T2m is substantially improved in the coupled run. This cold temperature bias could be related to an enhanced advection of moist air from the North Atlantic Ocean (Figure 5).

In July (Figure 14), the SST has a minor impact on the T2m. Both runs have very similar distribution pattern. The bias between the coupled run and uncoupled run has a positive distribution in the inland region, and a negative distribution in the coastal region. This spatial pattern is totally different from the January distribution. One of the possible reasons is that the lower atmosphere layer is unstable in January, and the air mass is intensified by an ample supply of heat and moisture from the Atlantic Ocean.

In October (Figure 15), the simulation is similar to January: the coupled run has a much larger warm bias. This bias feature could be broadly interpreted as resulting from the slightly enhanced pressure gradient in the coupled run which caused a strengthened flow of mild air from the Atlantic Ocean. The above monthly mean T2m analyses show that the SST has a more serious impact in the wet season.

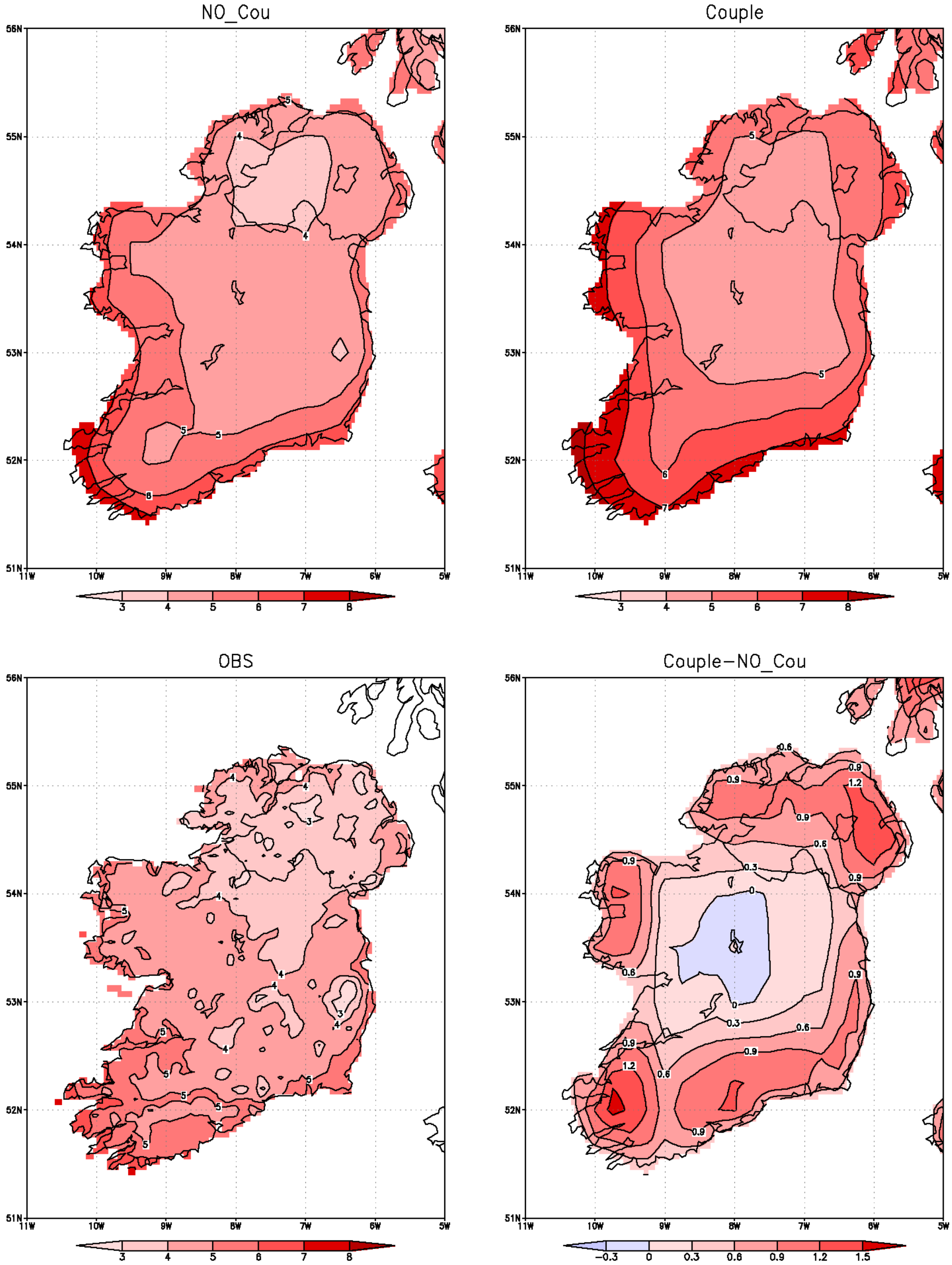


Figure 12 Average 2m temperature (1961-1990) for January (a) non-coupled run, (b) coupled run, (c) observation (d) difference between coupled and uncoupled runs

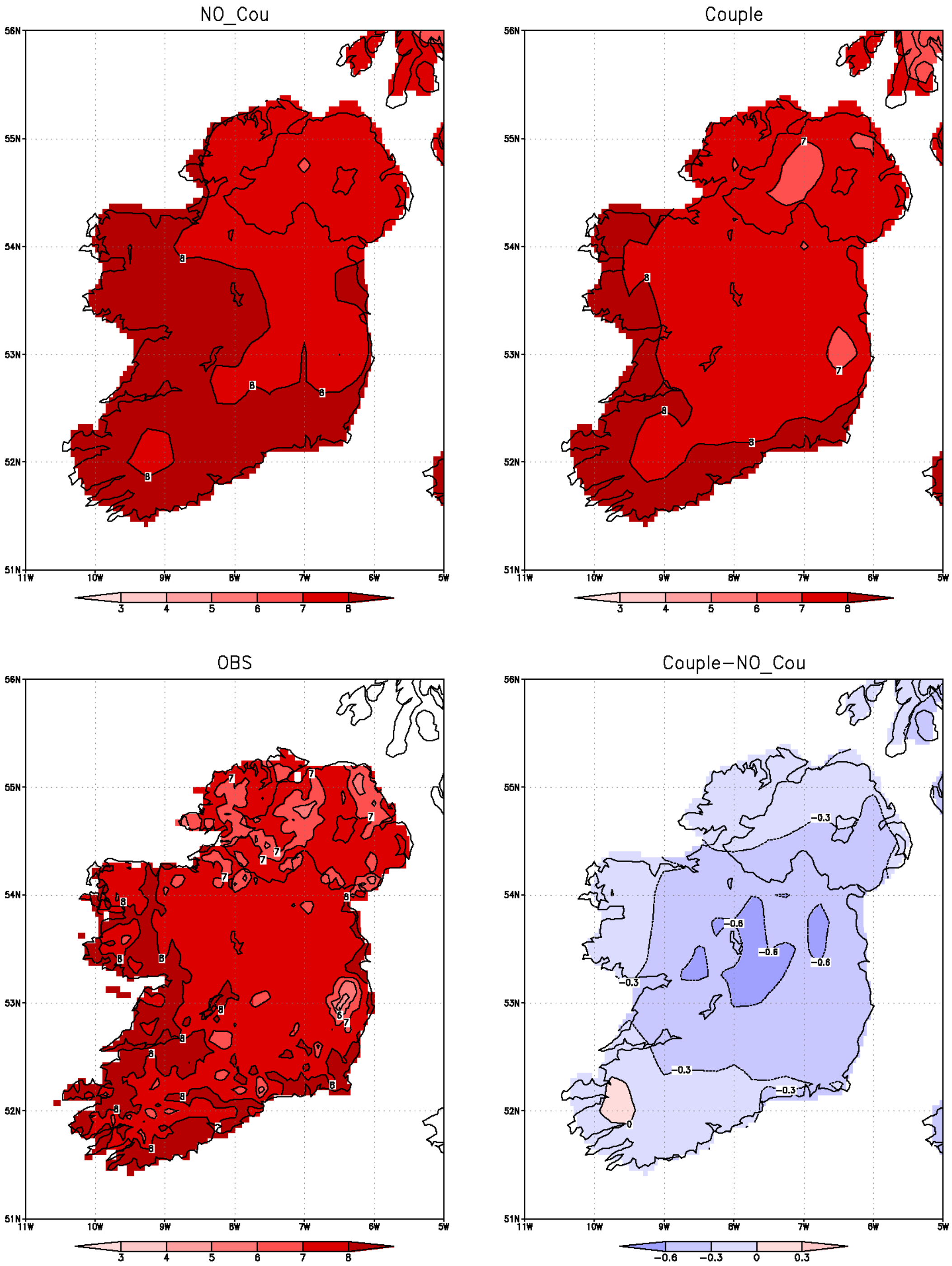


Figure 13 Average 2m temperature (1961-1990) for April (a) non-coupled run, (b) coupled run, (c) observation (d) difference between coupled and uncoupled runs

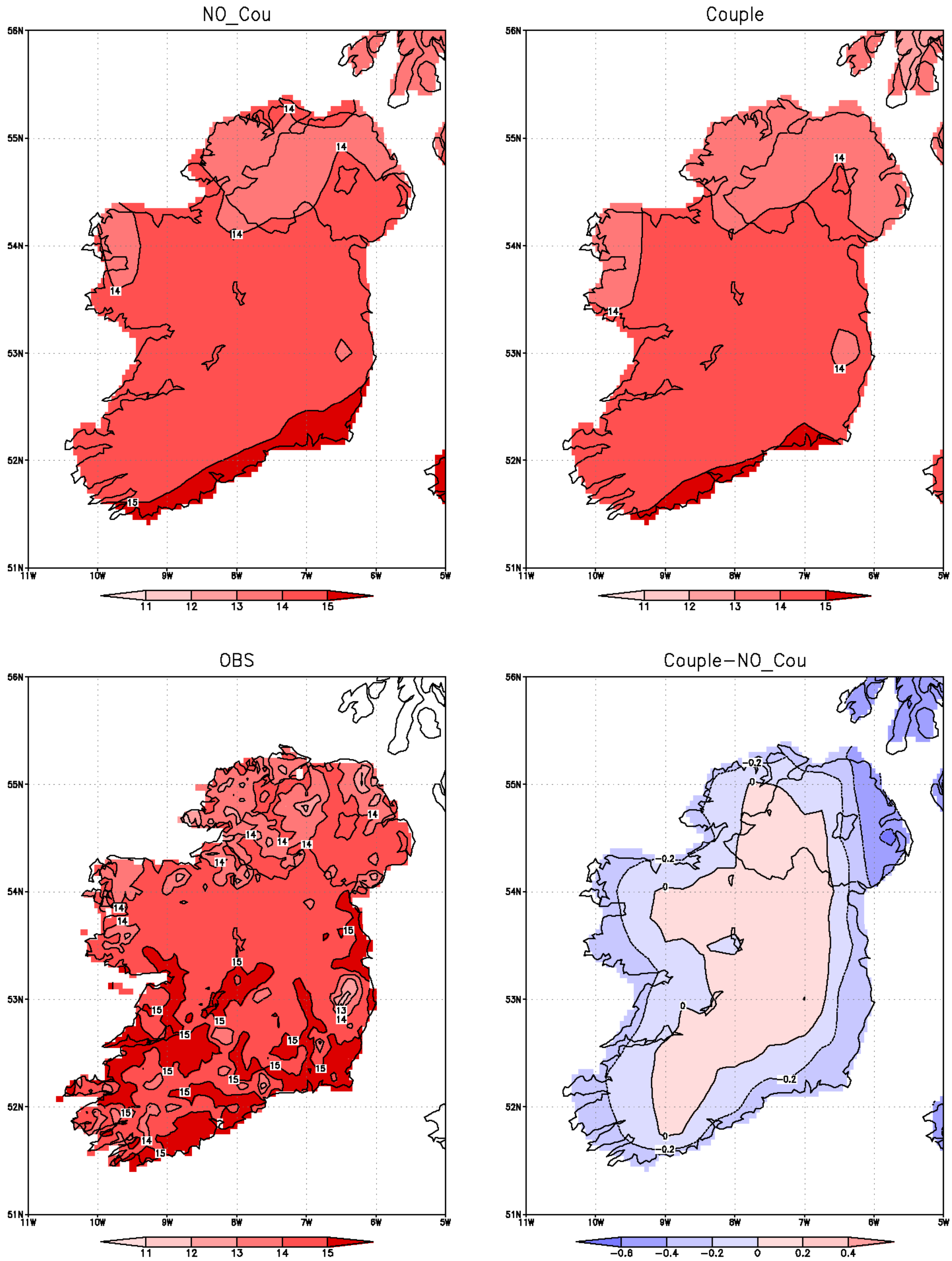


Figure 14 Average 2m temperature (1961-1990) for July (a) non-coupled run, (b) coupled run, (c) observation (d) difference between coupled and uncoupled runs

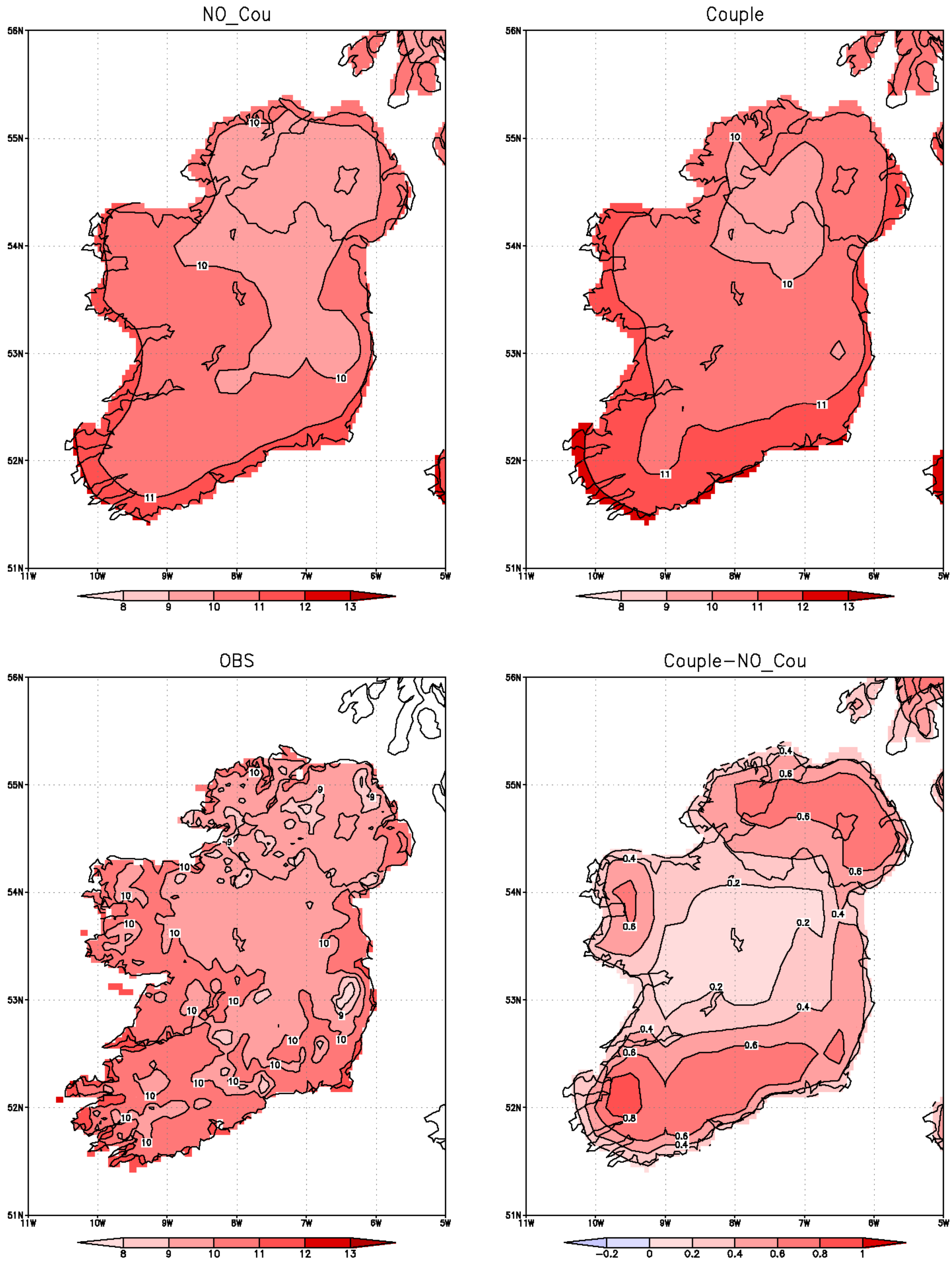


Figure 15 Average 2m temperature (1961-1990) for October (a) non-coupled run, (b) coupled run, (c) observation (d) difference between coupled and uncoupled runs

1.4 Conclusions

The RCA_NEMO model, an interactive flux coupled regional atmosphere-ocean model was developed in this study. This model, which combines two well known models, an atmospheric model (the Rossby Center Regional Climate Model, RCA) and and ocean model (NEMO), with the OASIS3 coupler, is fully parallel and can simulate the interaction between the atmosphere and ocean in climate simulations in a sophisticated manner.

The model has been demonstrated to run for 31 years without flux correction. Monthly mean output fields (1961-1990) for coupled and uncoupled models have been fully evaluated against analysis/observations. Mean sea level pressure, which is strongly associated with cyclone activity, has been reproduced fairly well by both models, except in April. The atmosphere-only run has a weaker pressure gradient over Ireland.

Precipitation as one of the most important factors in climate change study. However, it is difficult to capture in detail, due to its complexity. Although the spatial pattern of precipitation over Ireland is relatively simple, due to the impact of the Gulf Stream, the uncoupled regional atmospheric model cannot reproduce the pattern very well; the precipitation is overestimated in the lowland regions for all season. Compared with the UKCIP observation data, the coupled model more accurately represents the climate of Ireland. Not only are the basic characteristics reproduced by the coupled run but the wet bias in the lowland and dry bias in the southwest of Ireland are also improved. Although there is no straightforward relationship between the monthly mean precipitation and extreme events, the simulation of heavy precipitation events over land has also been improved by the coupled model.

Within contrast to the complexity of precipitation, the spatial pattern of surface temperature is relatively simple. The coupled model has different performance in different months. The 2m temperature has been slightly overestimated by the coupled model in wet months (January and October), perhaps as a result of the warmer SST from the ocean model. As stated above, the heat flux is transferred from the atmosphere model to the ocean model, while the SST is transferred from the ocean to the atmosphere model. According to the C4I simulations (C4I, 2006), the heat flux is always overestimated by the RCA model, which may cause warmer sea surface temperatures in the ocean model. However, the 2m temperature has been improved in the dry season (April and July).

The area chosen for validation of the coupled system in this study is rather small (little scope to allow for major departures from the driving boundary data), it would be interesting to do similar study over a bigger area, e.g. covering the whole North Atlantic and whole Europe. Since RCA model is a hydrostatic model and very higher resolution simulation (1~3km) requires non-hydrostatic model, the intention is to replace the atmospheric model with new non-hydrostatic HARMONIE model in the future. In conclusion, the coupled RCA_NEMO model is an effective tool for accurately reproducing the current climate of Ireland. Further improvements will be introduced in the next stage, and the model will be used to investigate climate change in Ireland under different climate scenarios.

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List of publications/reports from the project with complete references

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Summary of plans for the continuation of the project

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