UK-Japan Climate Collaboration MOU Project

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The UK-Japan Climate Collaboration project is using a model matrix composed of atmospheric resolutions at 135 km, 90 km and 60 km, and ocean models of 1 degree and 1/3 degree, developed on the Earth Simulator, to investigate the impact of resolving small-scale processes on large-scale mean climate and variability. Together with coupled control integrations of between 50-150 years, various idealised coupled climate change integrations and atmosphere-only integrations have been completed.

The composite structure and spatial distribution of tropical cyclones in the models improves as resolution is increased; model intercomparison studies indicate a consistent change of storm intensity and structure, though there are considerable differences in spatial distribution. Idealised climate change integrations indicate fewer but stronger storms when SSTs increase.

Multi-scale, multi-model intercomparisons are underway to understand both the large-scale, long term distributions, and the small-scale storm structures, with a view to impacts studies. ENSO in the high resolution coupled model performs realistically, with "delayed oscillator"-type variability, while the low resolution model has too much spectral power at longer timescales – use of parameter sensitivity tests and other integrations are beginning to reveal the mechanisms involved. Interactions between ENSO and interannual tropical cyclone distributions are also being investigated.

Rainfall extremes are represented more realistically in the highest resolution model, partly due to improved orography, and this leads to an improvement in seasonal river flows – both from better timing of snow melt and from the spatial distribution of rainfall. Coupled coastal processes also show sensitivity to both atmosphere and ocean resolution, leading to improved SST and cloud simulation at higher resolutions.

Keywords: resolution, climate, ENSO, tropical cyclone, extremes

1. Introduction

The Earth Simulator Center (ESC), NERC's National Centre for Atmospheric Science (NCAS-Climate) at the Walker Institute, and the Met Office Hadley Centre (MOHC) signed a Memorandum of Understanding for 5 years in 2002, to collaborate on advanced climate system research. Our aim is to produce ground-breaking climate simulations on the Earth Simulator, by developing high resolution models derived from the MOHC HadGEM1 model [1], including 150 km, 100 km and 60 km atmosphere, and 100 km and 30 km ocean resolution models. Higher resolution models will enable the representation of smaller scale processes, and it is the interaction of such processes with both the large-scale mean climate, and other emergent processes, that will help to better understand and reduce model uncertainty as well as building scientific capability. Such resolutions are also essential to represent regional detail for climate adaptation and impacts work. Our research will also help to define the appropriate resolution for the next generation MOHC models such as HadGEM3.

2. Project status

During the course of 2007, over 100 years of integration of the low (150 km/1˚) and high (100 km-1/3˚) resolution coupled climate models have been completed, together with 10 years of our new highest resolution coupled model (60 km-1/3˚). In addition we have completed many decades of global warming simulation using the 100 km-1/3° coupled model, as well as many simulations using the atmosphere-only model to study the precipitation extremes, tropical cyclones, land surface-soil parameters, the North Atlantic Oscillation, and the impact of the resolution of SST forcing on atmospheric processes.

This rich resource of model data continues to be exploited, in collaboration with the HiGEM consortium in the UK, to understand various climate processes - many papers have now been submitted based on this analysis ([2], [3], [4], [5]) with more to follow.

2.1 Model development and optimization

The primary model development and optimization effort has concentrated on the coupled model using the 60 km NUGAM model and the 1/3° ocean model. Various improvements to the model stability and efficiency have been made to enable us to complete over a decade of simulation.

2.2 Science

(a) ENSO

The 130+ year length of the coupled climate integrations enables analysis of long-period variability such as El Niño-Southern Oscillation (ENSO). ENSO is the primary interannual global climate signal: as such, it is vital to represent ENSO properly in order to understand global and regional variability. Continuing analysis is beginning to reveal the reasons why the high resolution model (HiGEM) simulates ENSO much more realistically than the low resolution model. Although both models show a "delayed oscillator" type of variability, the poorer mean state at low resolution means that the Kelvin wave which crosses the equatorial Pacific to terminate the warm event is much weaker. Together with different feedback processes in the South East Pacific, this leads to decadal power in the Niño3 SST in the low resolution model, compared to the 3-7 year variability seen in HiGEM and observations, and changes to the teleconnections patterns (Fig. 1). Several papers on this analysis are in preparation.

(b) Tropical cyclones

Typical, low resolution, climate models cannot be expected to simulate the full multi-scale range of processes that are the building blocks of phenomena such as tropical cyclones (TCs). These very intense and dangerous storms form in the tropics -where predictability is low- as a result of small scale disturbances which are only marginally resolved and interact with the large scale environment in a manifold of ways. The impact of such events, both in current climate and under future warming scenarios, is of great interest to the many regions affected by storm surge and landfall, as well as to mid-latitudes countries, which are affected by extra-tropical transition events.

The composite three-dimensional structure, as well as spatial distribution of tropical cyclones (from area diagnostics of track density, genesis, lysis) improve as model resolu-

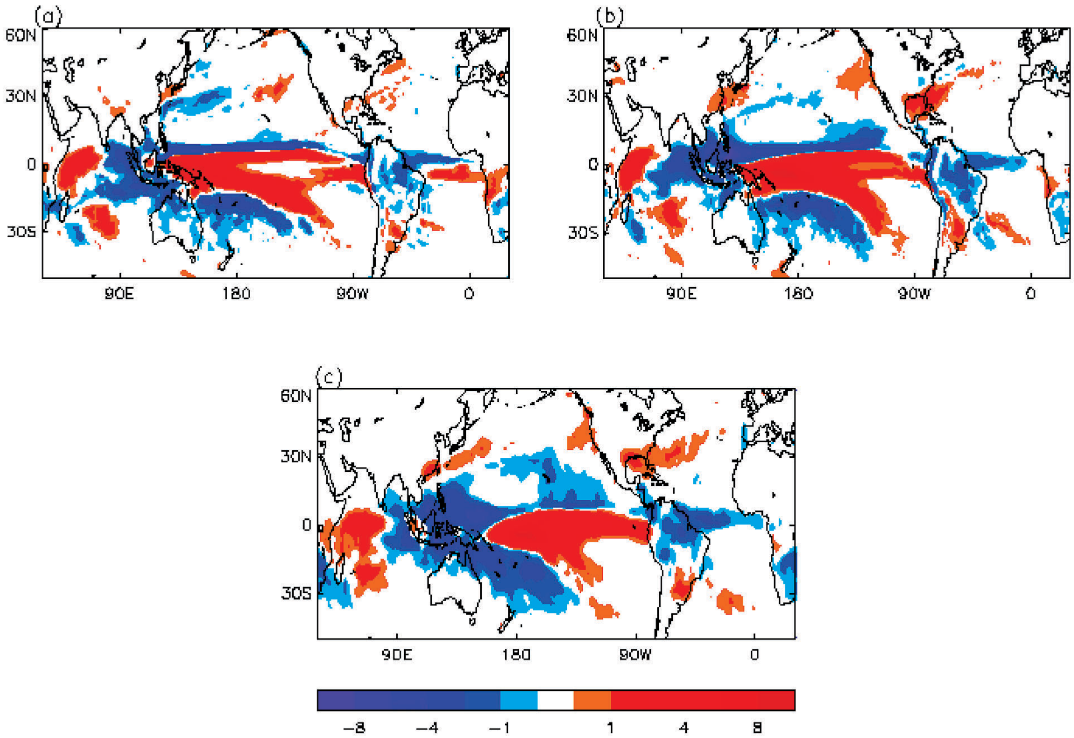

Fig. 1 The global anomaly in precipitation (mm/day) as a Dec-Jan-Feb average at the peak of El Niño for (a) low and (b) high resolution coupled models, and (c) CMAP observations.

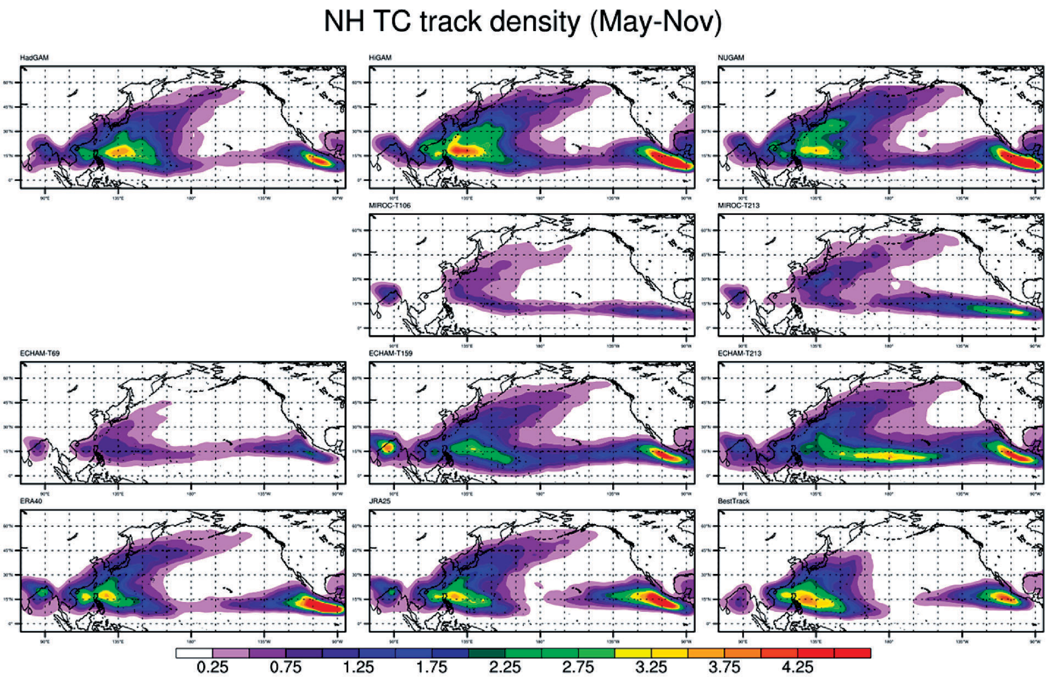

Fig. 2 Density of tropical cyclone tracks indicating the most frequently travelled paths, as simulated by different resolution atmosphere models at different resolutions, and by observational datasets. Top row: Hadley Centre models at 150 km, 100 km and 60 km resolution; 2nd row: MIROC models at T106 and T213 resolution; 3rd row: ECHAM models at T69, T159 and T213; observations/reanalyses datasets from ERA-40, JRA-25 and BestTrack.

tion is increased. The impact on geographic distribution is more modest, but at 60km resolution some notable differences emerge with the NUGAM model, especially in the (East) Atlantic basin. For storm intensity, histograms of central vorticity indicate a tendency for more severe storms in the higher resolution models. For storm structure TC (warm) core signatures indicate a contraction of the core as resolution increases, corresponding to a larger radial gradient in tangential wind speeds (also enhanced in the higher resolution model).

Intercomparison with the ECHAM5 and MIROC family of models indicates that the resolution dependence of storm intensity and structure is consistent across model formulations. However, storm intensity in the HadGEM family of models is substantially weaker when compared with equivalent GCMs (MIROC, ECHAM5) at comparable resolution; this may indicate model formulation deficiencies, e.g. in the form of targeted diffusion, which acts locally, limiting vertical motion to a low threshold. In general the spatial distribution of Tropical Cyclone activity seems to be heavily dependent on model formulation, less so on model resolution. Our three-model intercomparison reveals, on the other hand, that the HadGEM family of models has the largest skill at representing the geographical distribution of all aspects of TC activity, in all basins (Fig. 2).

A perturbation run (a uniform +4K SST increase) indicates a tendency to produce fewer but stronger storms, with a particular increase in the intensity distribution of precipitation - which is consistent with current IPCC results.

A joint UK-Japan publication on the impact of high resolution on tropical cyclone simulation is in preparation, with successors using the scenario simulations and analysis of the coupled model and links to ENSO.

(c) Precipitation extremes and river flow

Low resolution models are incapable of including sufficiently realistic orography (important for forcing localised precipitation distribution and hence for feeding the correct river basins), and cannot capture the precipitation extremes, due to poorly resolved convergence and vertical motion. Both effects will likely have an influence on river outflows, both in magnitude and seasonal cycle, and hence are important for water availability, flooding and drought impacts.

Concentrating on the Alps (for which a high-resolution (20 km) observational dataset is available) and Europe, the high resolution NUGAM (N216 = 60 km) model reproduces the spatial precipitation distribution more realistically, concentrating rainfall near significant orography and along coastlines. With regards to intensity/frequency signatures, quantile-quantile plots (Fig. 3) show that in autumn, a season of intense precipitation over the Alps, the models overestimate the low intensity precipitation events and underestimate the other events (>1-2 mm/day for HadGAM and HiGAM and >5 mm/day for NUGAM). However NUGAM

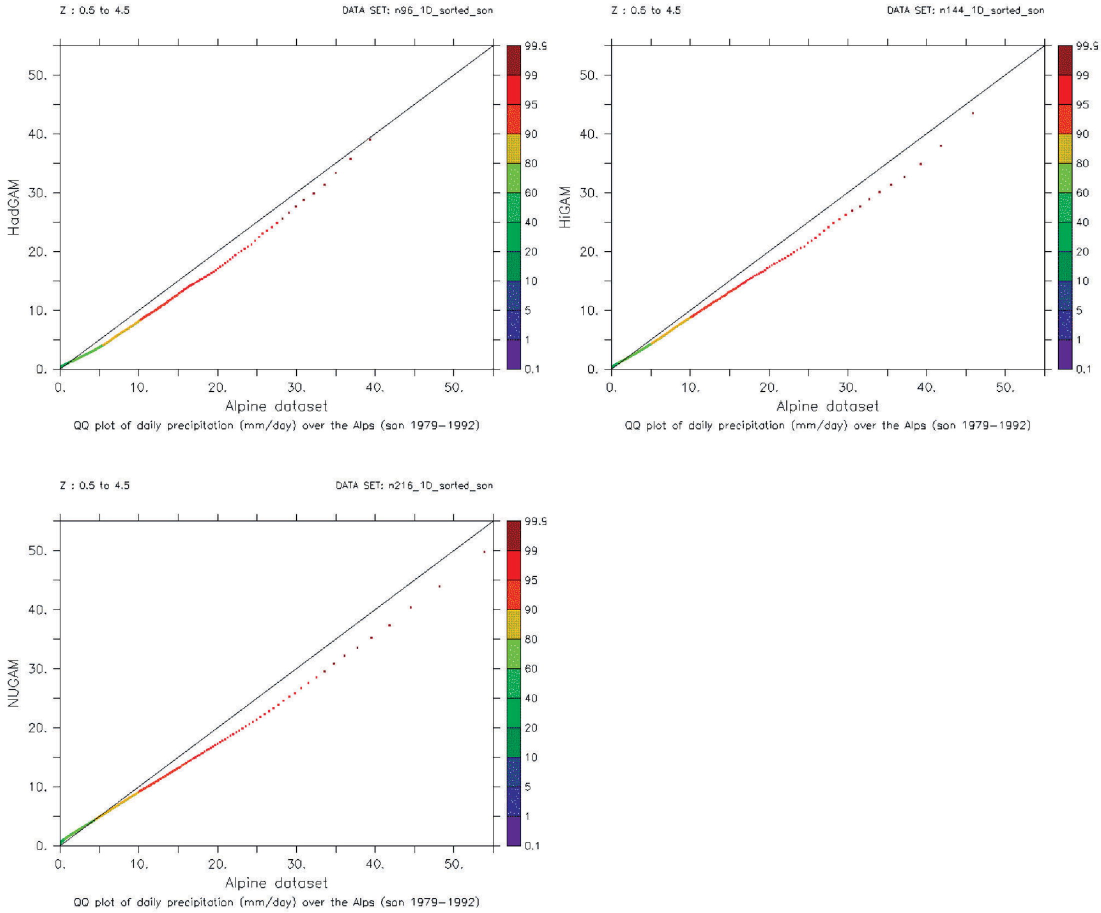

Fig. 3 Quantile-quantile plots showing the relationship between observed and modelled rainfall amounts for (a) low, (b) medium and (c) high resolution atmosphere-only models.

better represents extremes of rainfall, although not yet comparable with the high-resolution alpine dataset. The localisation of these extreme events is especially good in the high-resolution model.

Precipitation distribution, as well as the correct intensity spectrum, helps to improve the simulation of seasonal river flows in the Po, Rhine and Danube. Another contribution to the improvement in the simulation of river discharge is due to better timing in snow cover accumulation/loss on the N216 higher orography, which results in delayed spring snow-melt, in agreement with observations. Manuscripts are in preparation describing this work.

(d) Coastal coupling effects

Regions off the western coasts of sub-tropical continents suffer from warm biases due to insufficient stratocumulus cloud and too high ocean SSTs. These regions are important for fisheries and for ocean primary productivity (due to nutrient upwelling), and may well be sensitive to climate change.

The SST and cloud errors are reduced at higher resolution. This requires a combination of atmospheric resolution (for radiation and cloud processes, and possibly helped by improved orography in some places), and oceanic resolution (for stronger coastal upwelling and coastal SSTs) in order to improve the seasonal cycle of SST. Concentration of the ocean upwelling next to the coast seems to be crucial, which is simply not feasible at low resolution, for numerical stability reasons. The resolution of the ocean model in HiGEM also allows ocean eddies to be represented: transports associated with these eddies acting to widen the region of cold SSTs. Several manuscripts are being prepared to describe this work.

(e) North Atlantic Oscillation

The NAO is one of the primary modes of climate variability and a very important component of European winter climate. Dynamical models are often poor in relating SST anomalies to European weather, and the structure and strength of the NAO can be poor at low resolution.

The HiGEM model shows a stronger NAO with enhanced variability at low and high frequency, and analysis is continuing on the impact of driving atmosphere-only models with higher resolution SSTs. Ensemble simulations are also planned to look at seasonal and decadal predictability in different resolution models.

Aim and objectives for 2008

As well as continuing analysis on the above topics, there will be many new areas to consider in 2008. Analysis of the climate change integrations using the HiGEM1.1 model will begin. Several timeslice integrations will continue, using the SSTs from the HiGEM1.1 control and climate change runs to force the HadGAM and NUGAM models - these will allow the study of how higher resolution SSTs affect the simulation of tropical cyclones, the NAO and ENSO teleconnections. The impact of ENSO on the distribution of tropical cyclones will also be studied in the 130 year HiGEM integration, and the role of orography resolution will be studied in the NUGAM model.

Acknowledgements

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地球シミュレータセンター(ESC)、Walker研究所NERC大気科学ナショナルセンターとUK Met Officeハドレー気候研究センターは、5年計画の共同研究のための覚書(MOU)を締結し、2002年より共同研究を開始している。本ＭＯＵに基づくUK側の目的は、大気モデルとして150km、100kmおよび60km、海洋モデルとして100km、30kmの異なる解像度を組み合わせて、高解像度の大気海洋結合モデルMOHC HadGEM1を開発し、地球シミュレータ上において画期的な気候シミュレーション結果を生み出すことである。

本年度は、水平解像度が大気モデル150kmと海洋モデル1°(約100km)、大気100kmと海洋1/3°(約30km)の2つの大気海洋結合モデルの設定に対して100年以上のシミュレーションを実行し、さらに、大気60km海洋1/3°の高解像度の設定において、10年のシミュレーションを行った。さらに、大気100km、海洋1/3°の設定の結合モデルを使用して、数10年にわたる地球温暖化予測を行った。これらの成果は、文献[2], [3], [4], [5]にまとめられている。

ENSOに関しての解析では、高解像度によるシミュレーションは、周期や強度についての再現性がよく、テレコネクションパターンにおいても解像度が異なると結果に相違があることがわかった(図１)。熱帯低気圧の活性は、3種類のモデルHadGEM、MIROC、ECHAM5を比較すると、解像度よりむしろ、どのようなモデルを用いているかに依存するようである(図2)。また、低解像度では地形性の豪雨を再現する事は困難であり、アルプスやヨーロッパ領域において水平解像度60kmの大気大循環モデルNUGAMを使用してシミュレーションした結果、より現実的な降雨分布が得られた。しかし、降雨強度についてはバイアスがあるので、さらにモデルの改良が必要である。2008年は、さらにHiGEM1.1を使用したシミュレーションに加え、高解像度SSTが温帯低気圧、NAOやENSOなどのテレコネクションのシミュレーションにどのような影響を与えるかについての研究も進める予定である。

キーワード：resolution, climate, ENSO, tropical cyclone, extremes

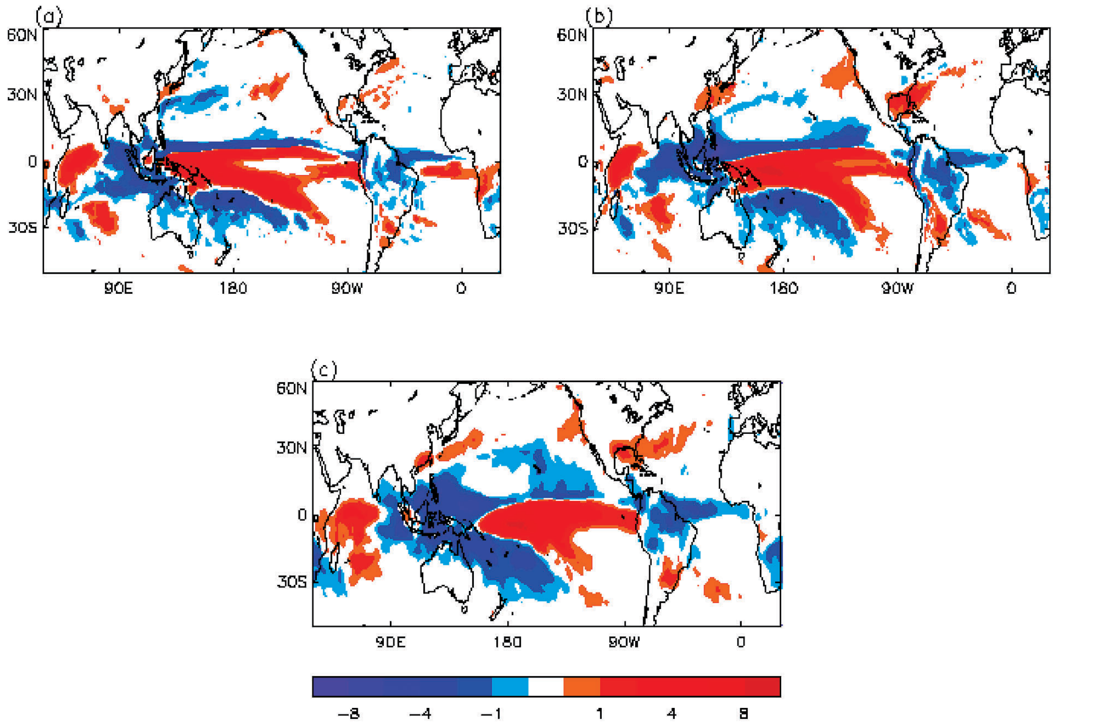

図1　全球における平均降雨量とEl-Niñoがピーク時の12月、1月、2月の平均降雨量との偏差(mm/day)。(a)は低解像度のシミュレーション結果における偏差、(b)は高解像度のシミュレーションの結果における偏差、(c)はCMAP観測データにおける偏差を示す。

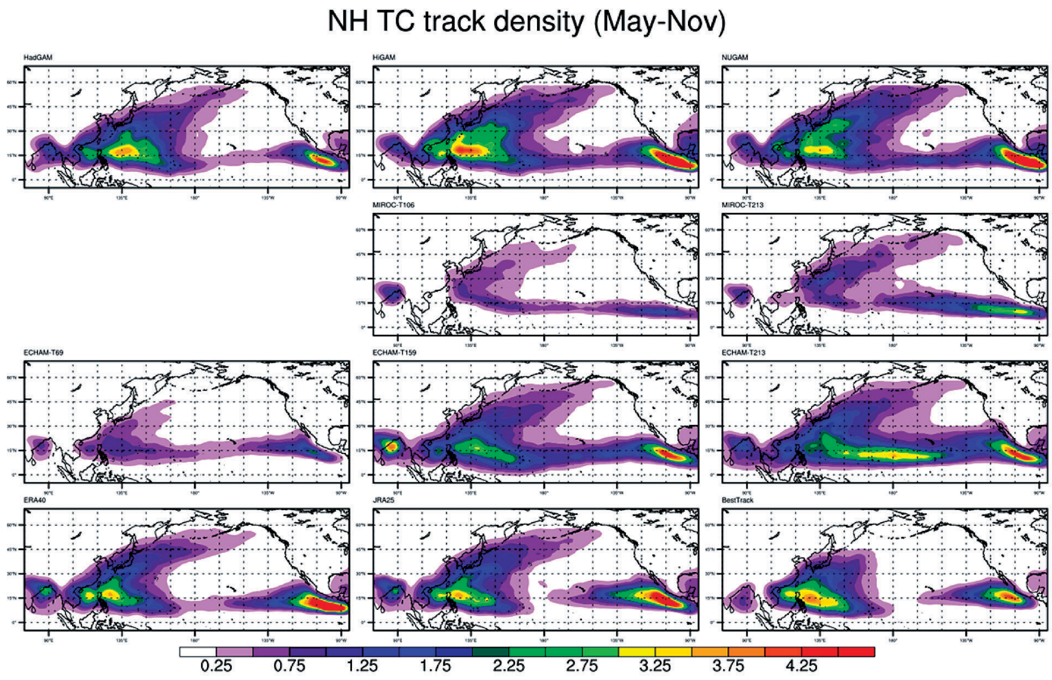

図2　熱帯低気圧の軌跡において各地域点が軌跡上に存在する頻度分布。異なるモデル、異なる解像度の結果を比較している。上段：ハドレーセンターモデルで150km、100km、60kmの水平解像度でのシミュレーション結果、2段目：MIROC(東京大学気候システム研究センターの大気海洋結合モデル)における水平解像度T106(約100km)とT213(約60km)の結果。3段目：ECHAM による水平解像度T69、T159、T213の結果、下段：ERA-40、ERA-25とベストトラックなど観測や再解析データより得られた結果。