Mesoscale ocean currents and improved climate modelling

The geological record depicts how climate changes over millennial scales have impacted species survival and ecosystem change. Forecasting future climatic conditions is therefore of great importance because of their potential impact upon many aspects of life on earth. Oceans account for around 70% of the Earth's surface and are the driving force behind our weather and climate system. **Professor Ping Chang's** research aims to deliver important insights into the co-dependency of coupled climate systems in the North Pacific and North Atlantic Oceans by improving the reliability of currently available prediction models.

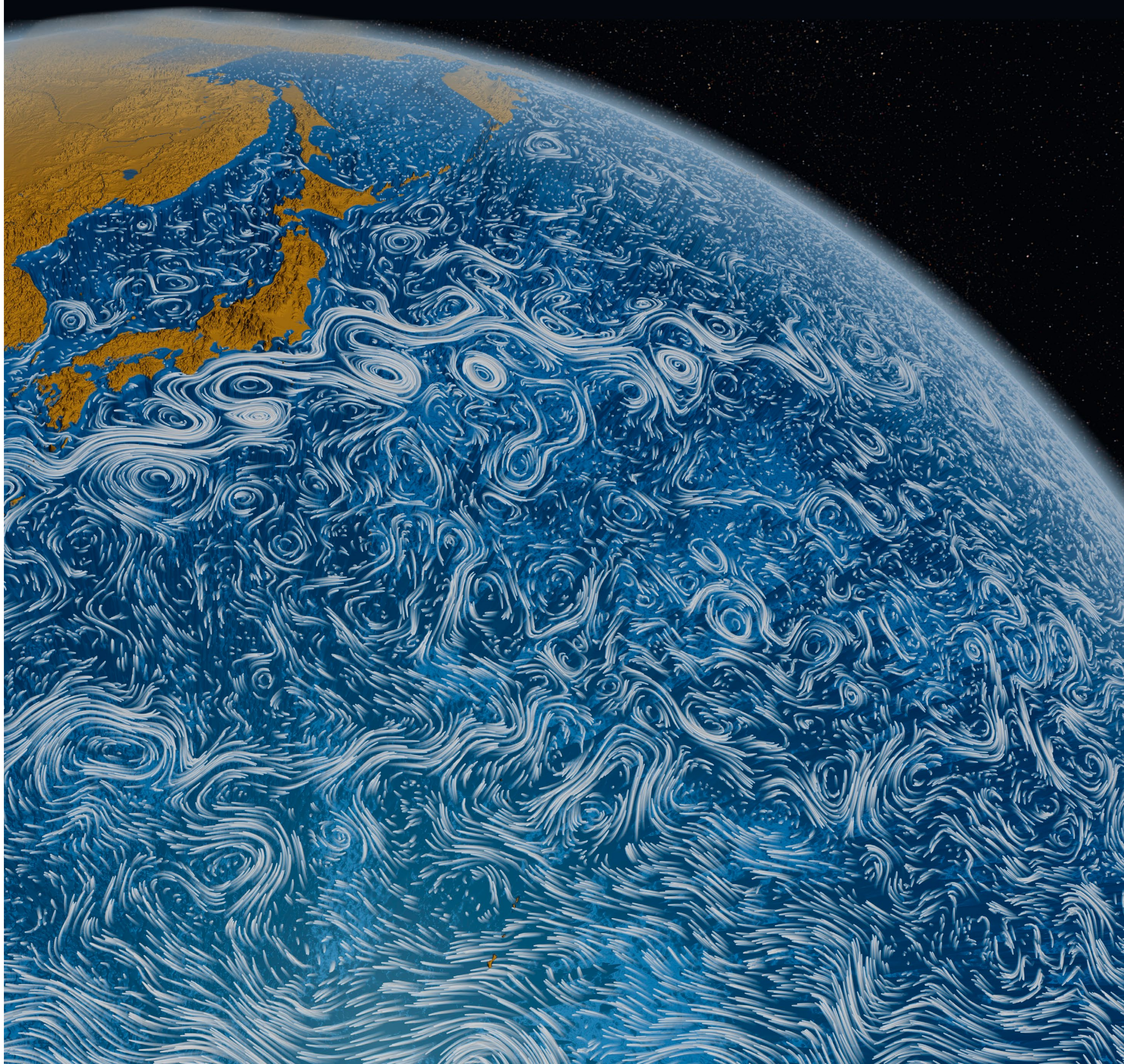
Just like the weather systems in the atmosphere, oceans also have their own chaotic circulation patterns, and both systems are intrinsically linked. Large-scale ocean circulation systems are often likened to a conveyor belt transporting heat from tropical regions to the poles. In most mid-latitude regions, interactions between the atmosphere and oceans are relatively passive, but where western boundary currents exist, the interaction is far more turbulent. The Kuroshio Extension Jet and Gulf Stream in the North Pacific and North Atlantic Oceans, respectively, are two such western boundary currents that exhibit dynamic instability and have the potential to influence atmospheric storm tracks. This dynamic instability is manifested as energetic ocean mesoscale eddies which are an important component of the ocean circulation system. They are currents acting over radial scales of 10s-100s km which are commonplace in global oceans. They are significant because they are like weather systems in the atmosphere, carrying over half of the kinetic energy within ocean circulation systems. Ocean mesoscale eddies include different types of circulation structures, including clockwise and counter-clockwise vortices and spirals, and can be thought of as discrete parcels of water with different characteristics from their surroundings.

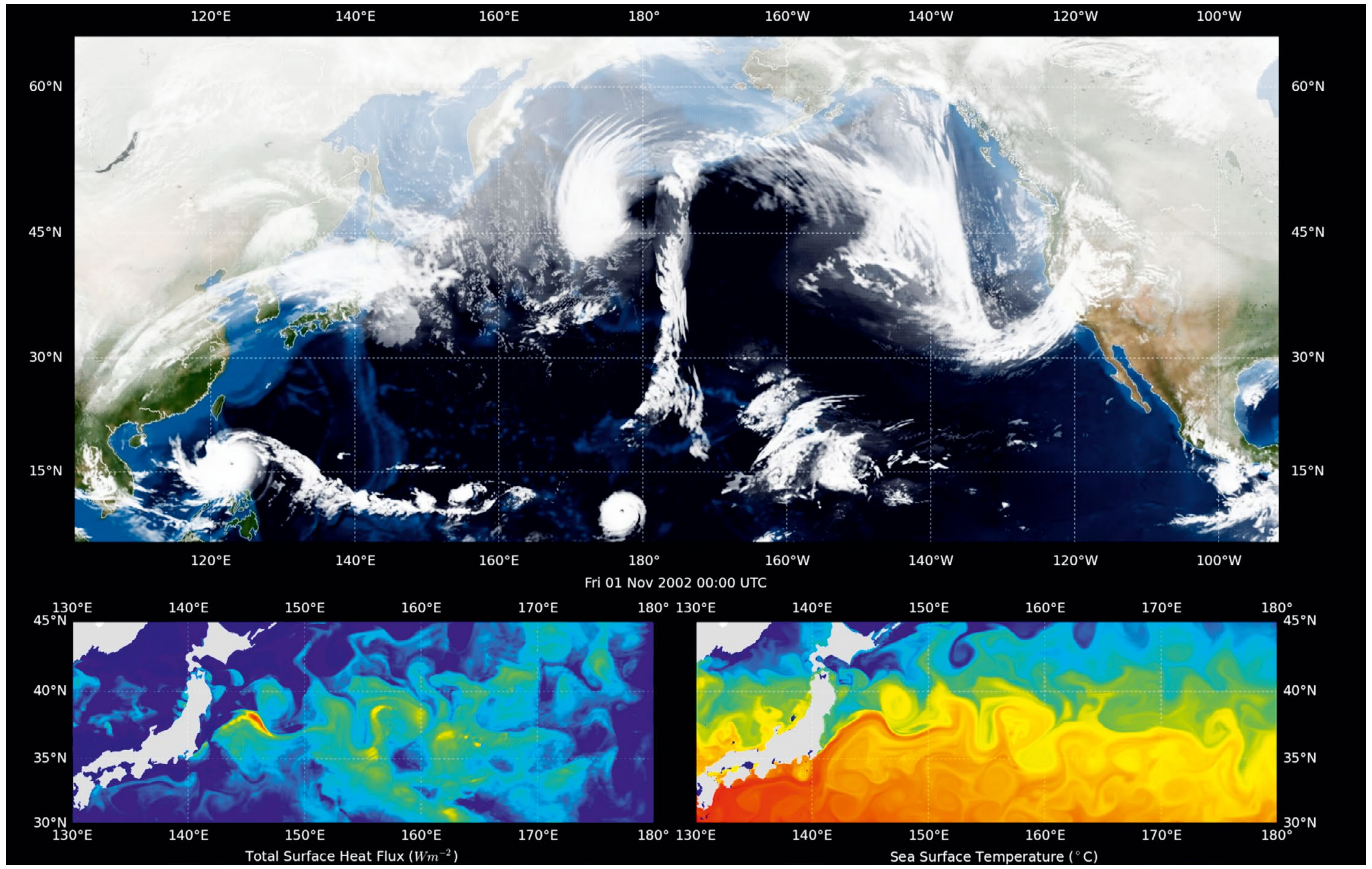
Past studies have acknowledged the importance of mesoscale eddies in mixing, for example, by conveying water of different salinity, carbon content or temperature. The interaction of ocean eddies with atmospheric systems can be important for the prediction of extreme weather because they carry strong sea surface temperature anomalies that can regulate energy exchange between the atmosphere and ocean. Their behaviour and influence on weather systems are less well understood but the research undertaken by Professor Chang and his collaborators aims to better understand ocean eddies and their implications for weather and climate systems.

FORECASTING THE FUTURE

Predictions for future climate often rely heavily upon climate models which generate computer simulations to forecast future scenarios. The complex and co-dependent nature of climate systems that include many interactions, for example, between atmosphere, oceans, the land surface and ice means that the models created may contain systematic errors, affecting the reliability of climate predictions. Being able to identify and address "bias" or error in climate models through better representation of the physical processes in action is important for improving reliability. Ocean mesoscale eddies act

Current climate models systematically underestimate the strength of oceanic fronts associated with strong western boundary currents, such as the Kuroshio and Gulf Stream Extensions"





A snapshot taken from a 9km regional coupled climate model simulation of North Pacific storm systems ainteracting with the Kuroshio Current and its eddies. Top panel shows the simulated outgoing longwave radiation (OLR) (Wm^{-2}); Lower-left and lower right show the net surface heat flux (SHF) (Wm^{-2}) and sea-surface temperature (SST) (C) over the Kuroshio Extension region. Ocean mesoscale eddies are clearly visible in SHF, indicative of strong feedbacks between ocean mesoscale eddies and atmosphere.

over an intermediate spatial scale when considering the entire area of an ocean, therefore higher resolution climate modelling down to scales of 10km or less is necessary to more accurately capture their impact upon weather and climate systems. Existing global climate models have spatial resolution of the order of 100km and at this resolution the interactions of ocean eddies with the atmosphere have been largely overlooked. This means that the current climate models adopted by the Intergovernmental Panel on Climate Change may not fully consider the impacts of eddies on climate systems and may also exhibit bias. Professor Chang's research specifically aims to identify and address bias in climate models by working at the mesoscale to develop improved climate models.

A CO-DEPENDENT SYSTEM

In order to improve upon current modelling capabilities, Professor Chang's team is undertaking a thorough analysis of the feedback mechanisms that take place between ocean mesoscale eddies and the atmosphere. Understanding the mechanisms of this feedback is challenging due to the fact that they occur at scales that are less trackable using current global modelling techniques. As such, new and improved models need to be developed. Professor Chang's team built a coupled regional climate model that approaches a resolution of 3km, which is much finer than for that of existing global models. Modelled results are validated and supported by detailed analysis of *in situ* field measurements and high-resolution satellite data. These satellite data can provide measurements of surface wind and sea surface temperatures which help to highlight the co-dependency between ocean eddies and near surface atmospheric flows and provide valuable input to the climate model.

Improved simulation of eddies in climate models may improve short-term prediction of weather patterns and long-term projection of climate change

APPROACH TO THE CHALLENGE

To examine and incorporate the role that ocean eddies in the North Pacific and Atlantic Oceans play in climate variability, Professor Chang's research team tests two main scientific hypotheses. The first asserts that the Kuroshiro and the Gulf Stream Extension currents located on the northwest side of the North Pacific and North Atlantic oceans respectively can influence storm tracks and weather patterns in both oceans. The second is that ocean mesoscale eddy atmosphere feedback is key to maintaining the aforementioned ocean currents. Undertaking computer simulations at higher resolution, this research has highlighted the important influence of ocean mesoscale eddies on near-surface patterns of wind and rainfall which has implications for regional climate. This was demonstrated when Professor Chang's team carried out atmospheric model simulations at resolutions of 27km and 162km in the North Pacific from October to March, both with and without impacts of ocean eddy induced sea surface temperature, forcing them to study the importance of ocean eddies. This research found that modelling at high resolution without the presence of eddies resulted in a shift in storm track. As such, in order to correctly simulate observed North Pacific storm track variability, the effects of oceanic and atmospheric coupling associated with ocean mesoscale eddies need to be included.

WHAT ARE THE IMPLICATIONS?

Clearly the work of Professor Chang and his researchers is of great significance, as inaccurate predictions of where storms and extreme weather events might occur or shift toward in future have major consequences for the regions they might affect. Incorporating an improved understanding of the importance of interactions between ocean mesoscale eddies and the atmosphere within climate models offers the potential to improve both storm forecasting and projections of how storm tracks may respond to future climate change. This can ultimately inform which parts of the world could be affected by storms both now and in the future and could further help to mitigate some of the social and economic impacts associated with extreme weather events.

Q&A

What excites you about climate science?

I am excited about climate science, because it seeks to understand origin, development, and alteration of regional and global weather patterns, which directly impacts daily life and has enormous social and economical implications. Climate science is extremely complex and requires multidisciplinary skill and knowledge about the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions amongst them. Advancing climate science also requires international collaboration. All these make the field both challenging and exciting.

You specifically mention the North Pacific and North Atlantic Oceans but where else to you think mesoscale eddies have the potential to impact weather systems?

Mesoscale eddies are also ubiquitous in the Southern Ocean, and have the potential to impact weather systems in the Southern Ocean. In the tropical oceans, mesoscale ocean eddies, such as Loop Current Eddies in the Gulf of Mexico, have been argued to affect hurricane genesis and development. The tropical oceans also have mesoscale sea surface temperature variability related to tropical instability waves in the ocean, which can influence the overlying atmosphere.

How does modelling at higher resolution improve climate prediction?

At sufficiently high resolutions, models can explicitly resolve small-scale phenomena, such as ocean eddies, that otherwise need to be parameterised. Uncertainties in parameterisations of subgrid-scale processes often leads to systematic errors and biases in climate models, causing forecast skill degradation.

Which areas of the world are potentially at risk from inaccuracies in storm track prediction?

North America and European countries are most likely to be affected by inaccuracies in storm track prediction, as extratropical cyclones are known to have devastating impact on countries in these regions.

How will ongoing climate change affect the status quo?

Recent decades have witnessed increases in some extreme weather and climate events, and increasingly strong evidence is emerging that indicates that some of these increases are related to ongoing climate change. Extreme events, such as tropical cyclones and winter storms, directly impact people's daily life and it is through their changes that most people experience climate change. Therefore, it is vital that we improve modelling capability of simulating, predicting and projecting extreme events.

Detail

RESEARCH OBJECTIVES

Prof Chang's current research examines the role of ocean eddies in the North Pacific and Atlantic and their implications for weather and climate systems in order to shed new light on causes of climate model biases along the Kuroshio and Gulf Stream fronts.

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BIO

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