ORGANIZED CONVECTION AND WEATHER PREDICTION ON SUB-SEASONAL TIME-SCALES

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Abstract:

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1. INTRODUCTION

A Thorpex interest group (IG2/IG10) has been set up in order to discuss issues relative to sub-seasonal time scales. Two major sources of predictability in the sub-seasonal time scale are the Madden-Julian Oscillation and stratospheric initial conditions. Therefore, most of the discussions within the group have focused on those two topics.

2. The Intraseasonal Oscillation (ISO)

The Intraseasonal oscillation (ISO: MJO in boreal winter and MISO in boreal summer) is the dominant mode of variability in the Tropics on time scales exceeding one week and less than a season. IG2-10 focused mostly on recent results regarding the impact of the ISO on the Extratropics, the prediction/predictability of the ISO and the importance of ocean/atmosphere coupling. Therefore, the present section discusses recent results regarding the impact of the ISO on Tropics/Extratropics (subsection 2.1), the importance of ocean-atmosphere coupling (subsection 2.2) and predictability of the MJO (subsection 2.3). Subsection 2.4 will present recent activities related to the ISO.

2.1 Impact of the ISO in the Tropical/Extratropics

Numerous studies have shown that it has a significant impact on the Indian and Australian monsoons, on the onset and development of an El-Nino event, and tropical cyclogenesis over the eastern Pacific and the Atlantic basin. Some studies (e.g. Kessler and McPhaden 1995) have suggested that it plays an active role in the onset and development of an El-Niño event. It has also an impact on the cyclogenesis in the eastern North Pacific (Maloney and Hartmann, 2000) , the Atlantic (Mo 2000, Maloney and Hartman 2002), the western North Pacific (Sobel and Maloney, 2000), the Australian basin (Hall et al, 2001) and the South Indian Ocean (Bessafi and Wheeler, 2006). Ferranti et al (1990) provided evidence that an improved representation of the MJO in the ECMWF forecast model (achieved in that case by relaxing the tropical circulation towards analysis) could lead to a significant increase of skill for the Extratropics after 10 days of forecast. More recently, Jones et al (2004) indicated that the tropospheric circulation has a predictability increased in average by about 2-3 days during an active phase of the Intraseasonal Oscillation as opposed to quiescent episodes of the oscillation. Recent studies have shown also an impact of the ISO on precipitation over Mexico (Barlow and Salstein, 2006), and China (Zhang 2006). Donald et al (2006) have shown that the MJO can influence daily rainfall patterns, even at high latitudes, via teleconnections with broadscale mean sea level pressure (MSLP) patterns. A study by T. Jung (personal communication) also highlights a significant impact of the MJO on the 500 hPa geopotential height in the extratropics and possibly on the presence of blockings. Therefore, it is important for extended-range forecasts to produce realistic MJO events.

2.2 Intraseaonal oscillation in numerical models

Climate models have generally a poor representation of the Madden-Julian Oscillation. Slingo et al (1996) found that none of the atmospheric GCMs that took part in the Atmospheric Model Intercomparison Project was able to capture the spectral peak associated with the MJO and a recent assessment of IPCC AR4 coupled models by Lin et al (2006a) showed only a slight improvement. A major problem with forecasting the intraseasonal oscillation is that the basic mechanisms for MJO (though there are plenty of theories proposed) are not fully understood, and the reason why MJO-like structures are somehow generated within some GCMs remains unclear.

2.2.1 Energy cycle of the MJO

To improve the predictability of the tropical intraseasonal variability (notably MJO), the generation and maintenance mechanisms of the IO must first be well identified by an objective observational analysis, then the performance of the models is verified against them. The energy cycle analysis provides such an objective method for identifying a mechanism. An analysis of the TOGA-COARE period by Yanai et al. (2000) appears to support a standard view of the MJO energy cycle: the potential energy generated by convective heating is converted into kinetic energy by buoyancy force (correlation of the vertical motion and the temperature anomalies), then it dissipates out. However, it turns out that MJO-like features simulated by global models do not necessarily follow this standard energy cycle. The analysis of Yano (2003, 2004) shows that, for example, not much energy is converted from the potential to the kinetic energies for a MJO mode in an ECMWF model, whereas convection does not generate much potential energy for MJO scale within a LMD model. In both models, an important role of nonlinear energy transfer is indicated. Particularly, most of the potential energy for the MJO is generated by a meridional deformation of the zonal temperature field in the LMD model. The ECMWF model even indicates that a negative dissipation is responsible for the generation of kinetic energy associated with MJO variability.

2.2.2 Intraseasonal oscillation in a dry atmospheric model

Lin et al (2006b) have shown that a dry atmosphere model can produce significant tropical intraseasonal variability (TIV) that has a Kelvin wave structure was found in the model atmosphere. Coherent eastward propagations in the upper troposphere velocity potential and zonal wind were observed, with a speed of about 15 m/s. Interactions between the tropical and extratropical flows are found to be responsible for the simulated intraseasonal variability. Wave activity flux analysis reveals that a tropical influence occurs in the North Pacific region where a northeastward wave activity flux is found associated with the tropical divergent flow in the western and central Pacific. In the North Atlantic sector, a strong extratropical influence is observed with a southward wave activity flux into the Tropics. The extratropical low-frequency variability develops by extracting kinetic energy from the basic mean flow and through interactions with synoptic scale transient eddies. The generation of the TIV in the dry model suggests a possible mechanism for the MJO. On the other hand, the fact that some of the key features of the MJO are missing in the dry model simulation indicates that tropical deep convective processes are indeed important for the observed MJO.

2.2.3 Convective parameterization

If it is shown that the feedback between convection and the large-scale water vapour field is crucial for the MJO (Maloney 1998,Grabowski 2004) then the challenge is to represent this correctly in convective parametrization schemes. This is not straightforward since increasing entrainment rates in conventional bulk mass flux schemes often suppresses parametrized convective activity at the expense of increased grid-scale activity and reduces a model's climate or forecast skill. The increased use of cloud resolving models will also be helpful to determine the vertical profile of heating that convective parametrizations must provide. The instantaneous profile of heating rates in current mass flux schemes is heavily constrained, and the vertical profile has been shown to be important for the representation of tropical large-scale variability. The important open questions are then how much stabilisation of the atmospere the convection-radiation interaction should provide (Raymond 2001), and how the parameterized heating profiles project onto the large-scale flow, and eventually produce a MJO via the wave mean-flow interaction (Hartmann 2001).

2.2.4 Importance of ocean/atmosphere coupling

Following TOGA-COARE, there were speculations that the MJO may be a coupled process (Flateau et al, 1997). More recently, a range of satellite, in-situ and reanalysis data (e.g. Zhang 1996; Woolnough et al 2000) confirmed a coherent signal in SST and surface fluxes which suggest that the MJO drives intraseasonal variability in the SST (see Hendon 2005 for a comprehensive review of air-sea interaction of the MJO). Shinoda and Hendon (1998) and more recently Bernie et al (2005) and Shinoda (2005) have shown in 1D mixed layer modelling experiments forced by observed fluxes from WHOI mooring during TOGA-COARE that the modulation of the diurnal cycle of SST by the intraseasonal variability in sea surface fluxes, has a significant impact on the intraseasonal variability of the SST.

Except for Hendon (2000) and Liess et al (2004), most recent studies (Wang and Xie 1998, Waliser et al 1999b, Kemball-Cook et al 2002, Fu et al 2003, Inness and Slingo 2003, Matthews 2004 and among others) claim that air-sea coupling can significantly improve the simulation of ISO compared to atmosphere-only models. Woolnough et al (2006) show that an improved representation of the mixing in the upper ocean, by using a high vertical resolution mixed-layer model, produced an improvement in the MJO forecast, particularly for the phases of the MJO where the convection is active over the Indian Ocean or West Pacific. Whilst air-sea coupling may strengthen the eastward propagating signal of the MJO, it does not improve its spatial distribution, seasonal cycle, and interannual variability (Zhang et al. 2006).

2.3 Predictability and prediction of the intraseasonal oscillation

It is not clear what is the theoretical limit of predictability of the Madden-Julian Oscillation, but statistical predictive models of the MJO display useful predictive skill out to at least 15-20 days lead time (Waliser et al 1999a, Lo and Hendon 2000, Wheeler and Weickmann 2001 ,Mo 2001). The skill of NWP models is often less than that of statistical prediction techniques (Waliser et al 1999a,Vitart 2003).

Waliser (2003) found that the NASA general circulation model (chosen because of its relatively realistic MJO representation) displayed potential predictability out to about 25-30 days for velocity potential at 200 hPa (VP200) and to about 10-15 days for rainfall in the eastern Hemisphere during periods of strong ISO activity, which suggests that there is scope for improving the prediction of the ISO in NWP models beyond what current statistical methods can achieve. More recently, Liess et al (2005) found that the upper limit of rainfall predictability associated with the MISO in the ECHAM5 AGCM could reach one month in some specific regions of the Asian-western Pacific domain. By conducting five ensemble predictability experiments with the NCEP seasonal forecasting system and by verifying them under the perfect model assumption, Reichler and Roads (2006) found that the potential predictability of the 200-hPa velocity potential in the tropics reaches about 4 weeks, but they found almost no predictability for model rainfall. Using an experiment framework similar to Waliser (2003) Fu et al (2006) showed that the MISO potential predictability was increased by about a week to 24 days when using a coupled ocean-atmosphere model than when using an atmosphere-only model.

However, in operational setting, the predictability of the ISO is likely to be shortened by errors existing in the initial and boundary conditions and the weaknesses of models to produce a realistic ISO. The predictive skill of the MJO (boreal winter ISO) in an old version (Hendon et al 2000; Jones et al. 2000) and a recent version (Seo et al 2005) of the NCEP model is only about 7-10 day when SSTs are fixed to climatology. More recently Vitart et al (2006) found that the ECMWF monthly forecasting system has useful skill in predicting the propagation of the MJO up to day 14, but the amplitude of the MJO decreases by about 50% after only a few days of forecasts. Using an improved representation of the mixing in the upper ocean, and using a different cloud parameterization the skill of he monthly forecasting system to predict the propagation of the MJO was increased by about 8 days.

The sensitivity of the MJO to perturbations of the initial conditions remains an important question. Using modified JMA's operational numerical weather forecasting system, Chikamoto et al (2006) found a growing tropical bred vector: dominant zonal wave number 1 components propagating eastward with phase speed of 30m/s. Its growth rate is 0.1/day. This result suggests that the tropical ISO is unstable to infinitesimal perturbations.

2.4 Current activities related to the MJO

2.1 MJO workshop at Trieste (13-17 March 2006)

THORPEX and WRCP promoted a workshop on the MJO (Trieste, 13-17 March 2006) to assess the current state of knowledge and predictive skill of multi-scale organised convection. The main recommendations from the workshop were (for more details, see report from J. Slingo, F. Molteni, M. Montcrieff and Mel Shapiro):

1) Develop metrics/description of the sub-seasonal, seasonal and interannual characteristics of the MJO and organised convection.

2) Promote collaboration on the use of NWP-type experiments for exploring error growth in simulations of organised convection and the MJO.

3) Promote international collaboration on high-resolution CSRM studies for exploring the upscale energy cascade associated with organised convection.

4) Integrate physical process studies of observed organised convection based on satellite and ground-based remote sensing and in situ measurements to provide improvements and validation of high resolution models.

5) Promote collaboration on forecast demonstration experiments to assess the value of improved MJO/organised convection simulations for prediction on timescales up to 4 weeks.

6) Consider the feasibility of a field experiment on organised convection guided by high-resolution modelling studies.

7) Endorse the need to maintain and enhance existing and planned satellite missions that measure tropical cloud and precipitation systems.

8) Develop the concept of seamless prediction in the particular context of the MJO, by forging links between THORPEX and WCRP

9) Promote the transfer of new knowledge and predictive skill of organised convection into improvements of operational NWP.

In addition, the report stressed two specific proposals:

- Shared development of a computational laboratory for advanced knowledge and predictive skill of organised convection, involving case studies, idealized simulations and theoretical interpretations.

- THORPEX/COPES year of coordinated observing, modelling and forecasting of organised convection and its influence on predictability. This proposal from D. Waliser intends to exploit the vast amount of new data and computational resources now available to characterize and diagnose tropical convection. The timeframe would be in 2008 for 1 year.

2.4.1 Experimental Prediction project:

As part of a strategy to assess current model subseasonal prediction capabilities and shortcomings, an experimental forecast and model development program was proposed that focuses on one of the key sources of untapped predictability, namely the MJO (Waliser et al, 2006). Several multinational forecast agencies and empirical modelers expressed interest in contributing near real time forecasts to a website that would display similar fields at similar lead times and in a common graphics format. The Physical Science Division agreed to host the site and a preliminary version came on line in August 2003. This site also hosts weather-climate discussions.
http: //www.cdc.noaa.gov/MJO

2.4.2 USCLIVAR subseasonal working group:

In spring 2006, US CLIVAR established a new Madden-Julian Oscillation (MJO) Working Group (MJOWG). The formation of this 2-year limited lifetime WG was motivated by: 1) the wide range of weather and climate phenomena that the MJO interacts with and influences, 2) the fact that the MJO represents an important, and as yet unexploited, source of predictability at the subseasaonal time scale, 3) the considerable shortcomings in our global climate and forecast models in representing the MJO, and 4) the need for coordinating the multiple threads of programmatic and investigator level research on the MJO. Near-term tasks involve the development of metrics for assessing model performance in both climate simulation and extended-range/subseasonal forecast settings as well as designing and coordinating multi-model experimentation and analysis to diagnose and improve model shortcomings and assess MJO predictability characteristics and present-day prediction skill. In addition, the WG will help to coordinate MJO-related activities across other programmatic bodies (e.g., GEWEX, International CLIVAR, Thorpex) and will explore the applications and potential user base for subseasonal predictions based on the MJO. For additional details, see www.usclivar.org/Organization/MJO_WG.html.

3. The Stratosphere-Troposphere Interaction

The prospect that the stratospheric circulation may exert some influence on the tropospheric circulation is of considerable interest to operational forecasting centres. For, if there is exists such a link between the stratosphere and troposphere, then the slower dynamics of the stratospheric circulation would increase the memory of the troposphere, making it potentially more predictable. The importance of understanding the coupling between stratosphere and troposphere is of course not restricted to sub-seasonal forecasting. In fact, it is one of the three scientific themes of SPARC (Stratospheric Processes And their Role in Climate; see for more information http://www/ atmosp.physics.utoronto.ca/SPARC/)

It was Boville (1984) who performed the first numerical experiments in this area. He clearly showed that slight changes to the stratospheric diffusion resulted in quite different tropospheric circulations as compared to the unperturbed model integration. In fact, the response closely resembled the spatial structure of the North Atlantic Oscillation. In more recent studies (Polvani and Kushner, 2002; Taguchi, 2003; Norton, 2003; Castanheira and Graf, 2003), using models of various complexity, these findings are confirmed. Polvani and Kusher (2002), for example, found that for sufficiently strong polar vortex conditions, the subtropical jet in the upper troposphere could move poleward by as much as 10 degrees and weaken at the same time. Also observational studies (Baldwin and Dunkerton, 2001) contributed to the idea that coupling between stratosphere and troposphere exist. Baldwin and Dunkerton showed that stratospheric anomalies of the Arctic Oscillation seem to propagate downward into the troposphere, where they, for example, alter the strength and location of the storm tracks. Interestingly, there is now also observational evidence that stratospheric preconditioning occurs prior to stratospheric final warming events (Black et al., 2006). Improving our understanding of these processes, aided with observations, may have consequences for sub-seasonal prediction.

Nowadays, there seems to be a consensus reached on the possibility to improve sub-seasonal forecasting of the tropospheric circulation by using knowledge of the stratospheric circulation (Christiansen, 2005; Charlton et al., 2003). In fact it is found that the best statistical forecasts are obtained when using (lower) stratospheric predictors as opposed to tropospheric predictors. Siegmund (2005) found that already with lead times larger than 5 days, the Z50 field proved to be a better predictor for Z1000 than Z1000 itself. Further, these statistical forecasts using such stratospheric predictors perform as well as state-of-the art dynamical seasonal forecast models for the troposphere.

The strong Stratospheric Sudden Warming (SSW) during January 2006 appeared to be unpredictable example of such a stratospheric event, which is not always the case (c.f. Mukougawa et al., 2005). Results of the ECMWF monthly forecasting system (Vitart, 2004) showed large differences in ensemble spread from one week to another. Especially, the collapse of the ensemble spread during the maturing phase of the SSW was a striking feature. More or less the same behaviour can be inferred from the JMA ensemble. It shows large spread among the members, which started 10 days before the event. Only a few days before the event the spread reduces substantially (Mukougawa, personal communication). For more information and diagnostics on SSW events since 1958 we refer to a recent developed website http:/www.appmath.columbia.edu/ssws. (Charlton and Polvani, 2006)

Recenty , so-called adjoint techniques have gained interest as a method to improve our understanding of stratospheric instabilities or mechanism that control the coupling between the stratosphere and troposphere (Adjoint Workshop, 2006). By employing this technique Jung and Barkmeijer (2006) determined optimal stratospheric forcing patterns that, with a small stratospheric amplitude, had a significant impact on the tropospheric circulation.

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