Wednesday, 18th September: ENSO Workshop

Talk: 20 mins + 10 mins questions

9h00-9h30:	Welcome and introduction (J. Boucharel)
9h30-10h00:	On ENSO theory (F-F. Jin)
10h00-10h30:	Recharge or not Recharge, that is the question (T. Izumo)
10h30-11h00:	Coffee break
11h00-11h30:	ENSO recharge oscillator dynamics: CMIP model biases and future projections (D. Dommenget)
11h30-12h00:	Change in seasonality of strong Eastern Pacific El Niño events with global warming in CESM-LE model (A. Carreric)
12h00-12h30:	Extreme El Niños and their projected changes (M. Lengaigne)
12h30-14h00:	Lunch break
14h00-14h30:	Predictability asymmetries between recharged and discharged states (J. Vialard, on behalf Y. Planton)
14h30-15h00:	A new metrics package for ENSO evaluation in CMIP models (E. Guilyardi)
15h00-15h30:	Addressing the complexity and diversity of ENSO with the redesigned Observing System in the Tropical Pacific (S. Cravatte)
15h30-16h00:	Separating the effects of background zonal and meridional winds on ENSO (A. Fedorov, **remotely**)
16h00-16h30:	Coffee break
16h30-17h00:	ENSO and tropical cyclones (J. Boucharel)
17h00-17h30	The extratropical response to the MJO tropical heating (N. Hall)
17h30-18h30:	Discussions
20h00	Workshop Dinner

Thursday, 19th September: ARiSE kickoff

Talk: 20 mins + 10 mins questions

9h00-9h30: Nonlinearities of the convective atmospheric response and ENSO flavours (B. Dewitte)

9h30-10h00: Nonlinear interactions between ENSO, TIWs and the annual cycle (J. Boucharel)

10h00-10h30: The importance of the atmospheric feedbacks for a realistic simulation of ENSO dynamics and asymmetry (T. Bayr, **remotely**)

10h30-11h00: Coffee break

11h00-11h30: ENSO representation in CNRM-CM5 and 6 (A. Voldoire, on behalf Y. Planton)

11h30-12h00: The DREAM model (N. Hall)

12h00-12h30: Observational analyses of the SST-convection relation for ARiSE (T. Izumo)

12h30-14h00: Lunch break

14h00-14h30: ARiSE project: overview, status and goals (J. Vialard)

14h30-16h00: Discussion 1:

- Everybody: briefly remind your objectives for the project
- Status of recruitments for the project
- Project timeline, 6-months and 1-year goals, post-meeting homework
- Project website, common repository for relevant publications, tool to exchange results?
- Next meeting?

16h00-16h30: Coffee break

16h30-17h30: Discussion: follow-up and wrap-up

Abstracts

On ENSO Theory (F-F. Jin)

Great progresses have been made in understanding, modeling, and predicting the basic features of the El Nino-southern Oscillation (ENSO) phenomenon characterized by interannual warming/cooling of the central to eastern equatorial Pacific and weakening/strengthening of tropical Pacific trade winds. The intensities, durations, patterns of sea surface temperature anomalies vary substantially from event to event. These differences often have significant global consequences. Climate models still exhibit large spread in simulating ENSO's time-space complexities. Better simulations and predictions ENSO require deeper understandings of the dynamics not only for ENSO's basic features but also for its complexity. This talk will briefly review progresses in terms of ENSO theory on ENSO's amplitude, phase-locking, asymmetry, pattern diversity, and multi-scale nonlinear interactions.

Recharge or not Recharge, that is the question (T. Izumo)

The Warm Water Volume (WWV), a proxy for the equatorial Pacific heat content, is the most widely used oceanic precursor of the El Niño Southern Oscillation (ENSO). The standard interpretation of this lead relation in the context of the recharge oscillator theory is that anomalous easterlies during, e.g. La Niña, favour a slow recharge of the equatorial band that will later favour a transition to El Niño. Here we demonstrate that WWV only works as the best ENSO predictor during boreal spring, i.e. during ENSO onset, in both observations and CMIP5 models. At longer lead times, the heat content in the western Pacific (WWV_W) is the best ENSO predictor, as initially formulated in the recharge oscillator theory. Using idealised and realistic experiments with a linear continuously stratified ocean model, and a comprehensive wave decomposition method, we demonstrate that spring WWV mostly reflects the fast Kelvin wave response to wind anomalies early in the year, rather than the longer-term influence of winds during the previous year. WWV is hence not an adequate index of the slow recharge invoked in the recharge oscillator. The WWV_W evolution before spring is dominated by forced Rossby waves, with a smaller contribution from the western boundary reflection. WWV_W can be approximated from the integral of equatorial wind stress over the previous ~ 10 months, thus involving a longer-term time scale than WWV main time scale (~ 3 months). We hence recommend using WWV_W rather than WWV as an index for the slow recharge before the spring predictability barrier.

ENSO recharge oscillator dynamics: CMIP model biases and future projections (D. Dommenget)

Abstract needed

Change in seasonality of strong Eastern Pacific El Niño events with global warming in CESM-LE model (A. Carreric)

While ENSO-induced extreme precipitation events are projected to increase in frequency in the future by the models participating in the Coupled Model Intercomparison Project (CMIP5), the underlying mechanisms are still debated. Here we investigate this issue using the simulations of the NCAR Community Earth System Model Large Ensemble (CESM-LE) Project. It is shown that, in the warmer climate, the duration of Eastern Pacific (EP) El Niño events peaking in winter is extended by two months. This is associated with a significant increase in events peaking during the February-March-April (FMA) period. This larger persistence of strong EP events is interpreted as resulting from both a stronger recharge process and a more effective thermocline feedback in the eastern equatorial Pacific due to increased mean vertical stratification. A heat budget analysis reveals that the reduction in seasonal upwelling rate is compensated by the increase in anomalous vertical temperature gradient within the surface layer, yielding an overall increase in the effectiveness of the thermocline feedback. The emergence of strong EP El Niño events peaking in FMA explains one-quarter of the increase in frequency of occurrence of extreme precipitation events, while one-third of the increase in extreme precipitation events is concomitant with weak-to-moderate El Niño events and therefore associated with the warmer mean SST. In CESM-LE, both the increase in mean SST in the eastern equatorial Pacific and the change in ENSO processes associated with differential warming between surface and subsurface (i.e. sharper thermocline) thus contribute to the increase in extreme precipitation events in the warmer climate.

Extreme El Niños and their projected changes (M. Lengaigne)

Abstract needed

Addressing the complexity and diversity of ENSO with the redesigned Observing System in the Tropical Pacific (S. Cravatte)

Sustained observations of the tropical Pacific Ocean have been a priority for nations around the basin since the 1980s, driven principally by the global climate effects of the El Niño/Southern Oscillation (ENSO), and by the demonstrated prediction skill based on ocean and air-sea interface observations. The TPOS 2020 project was initiated to improve our understanding of the TPOS capability, and to provide a stronger, more capable integrated approach with improved governance and management of risk. While the elements of the system were initially largely developed independently, a further integration of platforms is envisioned, including the Tropical Moored Array (TMA), Argo floats, and satellites, with each element contributing particular strengths.

The revisited TPOS network aims to accelerate advances in the understanding and prediction of tropical Pacific variability and its profound impacts at regional scales. It strived to balancing the requirements of maintaining a robust climate record (to be able to detect multidecadal changes in the tropical climate dynamics) against new requirements and needs to get insights into key processes for improving prediction systems. It aims in particular at sampling a diversity of climatic regimes, with enhanced capabilities for observing upper ocean and air-sea interactions. The new TPOS also considers the biological functioning of the tropical Pacific and its role on marine ecosystems and climate change, and includes the low-latitude western boundary currents and the eastern Pacific, where extreme El Niño events develop.

This presentation will discuss how the full implementation of the new TPOS will deliver many gains to better understanding the ENSO complexity and diversity.

A new metrics package for ENSO evaluation in CMIP models (E. Guilyardi)

The El Niño-Southern Oscillation (ENSO) is the dominant mode of interannual variability in the tropical Pacific and has far-reaching impacts on climate around the world. It is therefore key to ensure the correct simulation of ENSO in state-of-the-art climate models. A community-wide synthesis of metrics to evaluate the performance, teleconnections and processes of ENSO in coupled GCMs is now underway, led by the ENSO Metrics Working Group of the International CLIVAR Pacific Panel. This collaboration has already produced a new software package, written in Python, to facilitate multi-model diagnosis, evaluation, and intercomparison of ENSO simulations. The package assists in (1) identifying common model biases and their sources to guide model improvements; (2) assessing progress made from one generation of models to the next; (3) identifying models that are best suited for particular tasks; and (4) revealing emergent constraints among the diverse model responses to future climate change. The ENSO package is designed to interface with existing model evaluation software architectures, including PCMDI Metrics Package and ESMValTool. The capabilities of the package are demonstrated through application to the CMIP5 archive. A paper documenting the package and its application to the CMIP6 simulations is planned for the near future.

Predictability asymmetries between recharged and discharged states (J. Vialard, on behalf Y. Planton)

El Niño – Southern Oscillation (ENSO) is the dominant mode of interannual climate variability, with large environmental impacts at the global scale. With sea surface temperature anomalies (SSTA) reaching up to 4°C in the eastern equatorial Pacific, extreme El Niño events, such as in late 1982, 1997 and 2015, involve a complete re-organization of tropical convection with outsized societal impacts (e.g., tropical cyclones, floods, drought,...) relative to moderate El Niño events. It is hence of utmost importance to reliably forecast, at lead-time as long as possible, the occurrence and amplitude of ENSO. Despite an improved understanding of ENSO dynamics over the past decades, predicting the amplitude of ENSO events remains a challenge, especially at lead-times longer than 2-3 seasons. The "recharge-discharge oscillator" theory, used to describe ENSO dynamics, highlighted the role of the oceanic heat content averaged over the western equatorial Pacific as a robust long-lead precursor of ENSO. This theory is however essentially linear and does not account for the potential asymmetries existing between El Niño and La Niña events. Yet, observations suggest that the ocean preconditioning is a more efficient predictor for La Niña than for El Niño events. The observational record is short and therefore uncertainties on this asymmetry are large. Here we analyse the link between the oceanic preconditioning and ENSO in pre-industrial control experiments, and focusing on a set of eleven models that can reasonably reproduce ENSO variability. As suggested by observations, the discharge one year before ENSO peak in these models is a significantly better precursor of La Niña occurrence and amplitude than the recharge for El Niño. This asymmetry likely arises from (1) the asymmetry of the ocean preconditioning that promotes a larger influence on La Niña (larger discharge) than on El Niño (weaker recharge) and from (2) a nonlinear Bjerknes feedback that promotes the growth of El Niño rather than La Niña. These results are used to define sensitivity experiments in order to further investigate the mechanisms and predictability of ENSO events.

Separating the effects of background zonal and meridional winds on ENSO (A. Fedorov)

Changes in background zonal wind in the tropical Pacific are often invoked to explain changes in ENSO properties. However, the sensitivity of ENSO to mean zonal winds has been thoroughly explored only in intermediate coupled models, but not in coupled GCMs. The role of mean meridional winds has received even less attention. Accordingly, the goal of this study is to examine systematically the effect of both mean zonal (equatorial) and meridional (cross-equatorial) winds on ENSO using targeted experiments with a comprehensive climate model (CESM). Changes in the mean winds are generated by imposing heat flux forcing in two confined regions at a sufficient distance north and south of the equator. The heat flux perturbations in the opposite hemispheres are chosen of the same sign (to induce zonal wind change) or of different signs (to induce meridional wind change). We find that the strengthening of either wind component reduces ENSO amplitude, shifts the dominant El Niño flavor from the Eastern Pacific (EP) to the Central Pacific (CP), and inhibits meridional swings of the ITCZ. The effect of zonal winds is stronger than that of meridional winds. A stability analysis reveals that the strengthening of zonal and meridional winds weakens the ENSO key positive feedbacks, specifically the zonal advection and thermocline feedbacks, which explains these changes. Zonal wind enhancement also intensifies mean upwelling and hence dynamical damping, leading to a further weakening of El Niño. Ultimately, this study (Zhao and Fedorov 2019, minor revision, J.Climate) argues that the strengthening of background tropical winds in the past decades have contributed to the observed shift of El Niño characteristics after the year 2000.

ENSO and tropical cyclones (J. Boucharel)

One of ENSO's most important influences is its worldwide modulation of tropical cyclone (TC) activity. TCs impact millions of people annually and can devastate life and property. Because TC attributes (e.g., genesis, track and landfall locations, intensity) are largely controlled by large-scale atmospheric and oceanic conditions, TC activity can be substantially altered by ENSO, via ENSO's strong influence on both the atmosphere and ocean. Atmospheric modulations include changes in vertical wind shear, humidity, low-level vorticity, and the strength and position of subtropical highs. The ocean influences TCs via changes in sea-surface temperature and upper ocean heat content and vertical oceanic structure. This talk will focus on ENSO's influences on TC basins around the globe, including local effects and remote influences via atmospheric teleconnections. These basins include the western North Pacific, central-eastern North Pacific, North Atlantic, North Indian Ocean, and Southern Hemisphere (South Pacific and South Indian Ocean). We will also discuss additional factors that, together with ENSO, are important for TC prediction and projection, including other modes of natural climate variability and anthropogenic climate change.

The extratropical response to the MJO tropical heating (N. Hall)

The passage of the Madden Julian Oscillation in the tropical band is generally regarded as a source of mid-latitude predictive skill in the intraseasonal range. Several studies point to a systematic influence on forecast skill or on the occupation of low frequency flow regimes. The underlying physical mechanisms involve well known theories about teleconnections from a deep convective heat source in the tropics to a linear wave propagating to the mid-latitudes, and a resulting a flow anomaly that is potentially modified by transient eddy feedback.

In the case of the MJO, the sequence of events is complicated by several factors. The associated large scale tropical heating signature is a dipole. The dipole is propagating, and cycles through its phases on a timescale that is similar to the timescale associated with the response. The response itself is usually seen to be initially linear but can interact with transient systems and thereby project onto extratropical modes of variability. These factors can complicate the attribution of the response to a well identified phase in the tropical heat source. A few previous authors have addressed these problems making various choices in how to analyse observational data or model results.

In this presentation the DREAM - Dynamical Research Empirical Atmospheric Model will be used to examine many aspects of the extratropical response to a moving cyclic MJO-like tropical heat source. DREAM consists of a dynamical core forced by empirically derived source terms to perform either as a simple GCM or as a perturbation model about a fixed basic state.

We will examine the sensitivity of the extratropical response to the MJO to factors such as propagation characteristics, nonlinearity and transient feedback. Different factors come into play on different timescales and we consider the appropriate response timescale in the case of a cyclic moving source with a 40-60-day period.

We find that it is important to take into account the mobile nature of the source, and that nonlinearity plays an important role for certain phases of the MJO source. The relationship between the MJO phase and the remote influence is also sensitive to the maturity of the response.

Nonlinearities of the convective atmospheric response and ENSO flavours (B. Dewitte)

Abstract needed

Nonlinear interactions between ENSO, TIWs and the annual cycle (J. Boucharel)

Motivated by a recent active period of Tropical Instability Waves (TIWs) that followed the extreme 2015/2016 El Niño, we developed a stochastically forced linear model for TIWs with its damping rate modulated by the annual cycle and El Niño Southern Oscillation (ENSO). The model's analytical and numerical solutions capture well the observed Pacific TIWs amplitude variability dominated by annual and ENSO timescales as well as their combination. This formulation allows assessing the nonlinear rectifications of TIWs activity onto the annual cycle and ENSO through, for instance, TIWs-induced ocean heat transport. In particular, this framework allows deriving a new method to quantify the seasonally modulated nonlinear feedback from TIWs onto ENSO. It also has implications for a potential new teleconnection pathway for ENSO to impact the climate system through nonlinear rectification in the atmospheric responses to TIWs. Moreover, our approach serves as a general theoretical framework to quantify the deterministic variability in the covariance of climate transients owing to the combined modulation of the annual cycle and ENSO.

The importance of the atmospheric feedbacks for a realistic simulation of ENSO dynamics and asymmetry (T. Bayr)

Based on observations and simulations of the 5th phase of Coupled Model Intercomparison Project (CMIP5), we investigate how well ENSO dynamics and asymmetry are simulated, with a special focus on the contribution of the amplifying and damping atmospheric feedbacks on the SST anomaly growth during ENSO events. We present a new method based on an Offline Slab Ocean SST that gives a quantitative measure about the error compensation between the wind-SST and the heat flux-SST feedbacks, that are both strongly underestimated in most CMIP5 models. We show by means of this method that ENSO is not predominantly wind-driven in many models, as observed; instead ENSO is significantly driven by a positive shortwave radiation feedback, while it acts as a damping in observations. In the most biased models, a positive shortwave-SST feedback contributes to the SST anomaly growth to a similar degree as the ocean dynamics.

Further we highlight by means of this method, that climate models with strong wind-SST and heat flux-SST feedbacks and a nonlinear shortwave-SST feedback tend to simulate more realistic ENSO dynamics and are therefore able to simulate the asymmetry between El Niño and La Niño properly. Our results suggest that a broad continuum of ENSO dynamics exists in state-of-the-art climate models and that the equatorial cold SST bias, that is present in many CMIP5 models, hampers a realistic simulation of ENSO dynamics and asymmetry.

ENSO representation in CNRM-CM5 and 6 (A. Voldoire, on behalf Y. Planton)

Abstract needed

The DREAM model (N. Hall)

DREAM is a model of intermediate complexity based on a spectral primitive equation model of the global atmosphere. Apart from some simple damping and diffusion, all physical processes have been replaced by forcing functions that have been empirically derived from reanalysis data. They vary spatially and can be prescribed in perpetual mode or with an annual cycle (Hall et al, 2019).

DREAM is thus a relatively cheap and simple model that still has a fairly realistic climatology when run as a GCM. It can also be used as a perturbation model with a fixed basic state, and can be set up to diagnose linear normal modes or responses to forcing anomalies. DREAM can also be nudged towards observations in selected regions to diagnose the dynamical impact of observed flow anomalies.

In this talk I will first give a brief explantion of how DREAM works, and then show examples of research using some of these techniques, which will be used in the ARiSE project to investigate nonlinearities in the atmospheric response to El Niño SSTAs.

Observational analyses of the SST-convection relation for ARiSE (T. Izumo)

Abstract needed

Overview of the ARiSE project (J. Vialard)

The El Niño Southern Oscillation (ENSO) is the leading mode of interannual climate variability on earth. It consists of irregular, alternating phases of warm (El Niño) or cold (La Niña) Sea Surface Temperature (SST) anomalies in the tropical Pacific Ocean, but has global climate impacts through atmospheric teleconnections. It is predictable 2-3 seasons in advance, so ENSO is also a major source of global seasonal climate predictability. State-of-the-art ENSO forecasts however have not performed well for "extreme" El Niño events such as those in 1982-83, 1997-98 or 2015-2016. With climate projections suggesting that such extreme events may become more frequent, it is vital to improve our understanding of the processes involved in these ENSO events.

ENSO grows through the Bjerknes feedback, a positive feedback loop between the ocean and the atmosphere. In this feedback loop, an SST anomaly induces deep atmospheric convection. The resulting changes in surface wind drive an ocean response that strengthens the initial SST anomaly, allowing ENSO events to grow. While the oceanic component of this feedback loop is well understood, there are far fewer studies of its atmospheric component. Yet, the atmospheric component of the Bjerknes feedback exhibits strong non-linearities which have been recently suggested to play a key role in extreme El Niño events. Deep convection indeed only occurs for SSTs above ~27.5°C, implying that the atmosphere will be more responsive to SST fluctuations in the warm western Pacific than in the colder eastern Pacific. The conceptual models used to understand ENSO do not account for this non-linearity, or for other potentially-important sources of atmospheric non-linearities such as heat flux feedbacks. Additionally, the capacity of Coupled General Circulation models (CGCMs) used for ENSO research and forecasting to reproduce the non-linear atmospheric response to ENSO SST anomalies has not been systematically evaluated so far. Previous work suggests that this non-linearity likely plays a key role in linking the models' systematic biases to their documented underestimation of the Bjerknes feedback.

Developing tools to quantify, understand and model the non-linear wind response to ENSO SST anomalies is thus a vital prerequisite to a) understanding extreme El Niño mechanisms and b) being able to diagnose the source of ENSO biases in CGCMs. ARISE proposes to use observational analyses and a hierarchy of atmospheric and coupled models (from conceptual to general circulation models) to better describe the non-linear atmospheric response to ENSO and its impact on ENSO properties, and in particular extreme El Niño events.

In Work Package (WP) 1, we will use observations and two types of atmospheric GCMs to produce a seasonally-dependent transfer function between SST and wind stress variations, and explore its non-linearity. In WP2, we will develop the simplest possible atmospheric model that encapsulates essential dynamical and thermodynamical non-linearities for ENSO, and investigate their impact on ENSO, in an intermediate and a conceptual model. In WP3, we will use the results from the previous WPs to improve our understanding of ENSO in CGCMS: a) we will diagnose the specific mechanisms of extreme El Niños in a CGCM; b) we will evaluate links between atmospheric non-linearities and ENSO biases in the CMIP database. This will provide tools for improving ENSO representation in state-of-the-art CGCMs used in forecast mode.

The current project gathers a unique blend of oceanographers and atmospheric scientists with good expertise in ENSO, including developers of some models used in the project. This project also benefits from the support of several renowned international collaborators on their own funds. ARISE is a unique opportunity to make a step change in our understanding of tropical air-sea interactions, the role of the atmosphere in ENSO and its diversity with potentially large societal impacts.