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RESEARCH STATEMENT

My research focuses on ocean-atmosphere and climate dynamics with an emphasis on large-scale tropical variability, e.g. the El Niño Southern-Oscillation(ENSO) or Madden-Julian Oscillation (MJO). This research involves dealing with geophysical fluid dynamics theory, applied mathematics, data analysis, numerical modeling, and more recently machine learning. For example I developed numerous dynamical and statistical models for the ENSO and MJO, at varying levels of complexity. Below are some of my representative works in chronological order.

Ocean stratification and climate change. Climate projections predict that the ENSO may increase in strength with climate change, but they remain uncertain due to compensating atmosphere and ocean feedbacks. Increased ocean stratification in particular may strongly strengthen the ENSO (Fig 1). I studied this mechanism with a multi-baroclinic representation of the ocean that better describes stratification changes than conventional shallow-water representations. I demonstrated the process with a theoretical framework, analyzed parameter sensitivity and implemented data assimilation strategies. See Thual et al. (2011).

MJO intermittency theory. The Madden-Julian Oscillation (MJO) is a 40-to-50 day oscillation in the equatorial troposphere that alternates periods of increased and decreased convection and that impacts subseasonal-to-seasonal climate forecasts across the globe. One major theoretical challenge is to understand how convection builds up across scales to control the MJO's characteristics. I extended an MJO model with an idealized stochastic parameterization for convection to understand the MJO's irregularity and intermittency as well as its organization into wavetrains (Fig 2). I also extended the framework to study the MJO's vertically titled structure, its modulation by the seasonal cycle as well as its off-equatorial propagation in boreal summer. See Thual et al. (2014).

El Niño and wind bursts. A major limit to El Niño predictability is the interaction with fast fluctuations in the atmosphere called wind bursts that shape El Niño's onset and strength. I developed a theoretical framework to study these interactions consisting of a dynamical model of the equatorial Pacific coupled to a stochastic wind bursts parameterization. The model was used for a variety of hypothesis testing, e.g. to understand how wind bursts may generate extreme Niño events (Fig 3), the processes for El Niño diversity and seasonality as well as the interplay with MJO variability. See Thual et al. (2016).

ENSO complexity and the Walker circulation. The El Niño Southern-Oscillation (ENSO) refers to the alternation between El Niño, La Niña or neutral conditions in the equatorial Pacific. Despite major worldwide impacts, it remains difficult to predict due to the so-called ENSO complexity that is fundamental nonlinearities as well as marked changes in characteristics from one event to the next. I developed a conceptual model to demonstrate that ENSO complexity is controlled by the zonal shifts in the background circulation of the Pacific or so-called Walker circulation. The nonlinear process may explain the diversity in observed warming and cooling patterns (Fig. 4) as well as the asymmetry in strength between El Niño and La Niña. The spatial shifting concept opens broad perspectives for the study of ENSO dynamics and teleconnections as well as its representation by climate models. See Thual and Dewitte (2023).

Video Diffusion Models for MJO Generation. While several theories exist for MJO dynamics, it is hard to compare them to the rather intermittent and disorganized MJO observations. I developed a video diffusion model for the MJO conditioned on key theoretical metrics (Fig 5). The model can generate idealized yet realistic MJO sequences (e.g. a perpetual MJO with constant period), which helps bridge theory and observations. See Thual et al. (2026).

Research Goals. The broad goal of my research is to improve understanding and prediction of climate dynamics and climate climate change. For this I want to contribute to a better understanding of large-scale tropical dynamics from both a theoretical and applied standpoint.

Representative papers:

- *Thual, S. and Luo. F (2026). Climate Prompting: Generating realistic Madden-Julian Oscillation from Theoretical Conditioning using Video Diffusion Models. In review*
- *Thual, S. and B. Dewitte (2023). ENSO complexity controlled by zonal shifts in the Walker circulation, Nature Geosciences, doi: s41561-023-01154-x*
- *Thual S., A.J. Majda, and N. Chen (2016). A Simple Stochastic Model for El Nino with Westerly Wind Bursts. PNAS, 113:10245-10250.*
- *Thual S., A.J. Majda, and S.N. Stechmann (2014). A Stochastic Skeleton Model for the MJO. J. Atmos. Sci., 71: 697-715.*
- *Thual S., B. Dewitte, S.-I. An, and N. Ayoub (2011). Sensitivity of ENSO to stratification in a recharge-discharge conceptual model. J. Climate., 4:4331-4348.*

Figures:

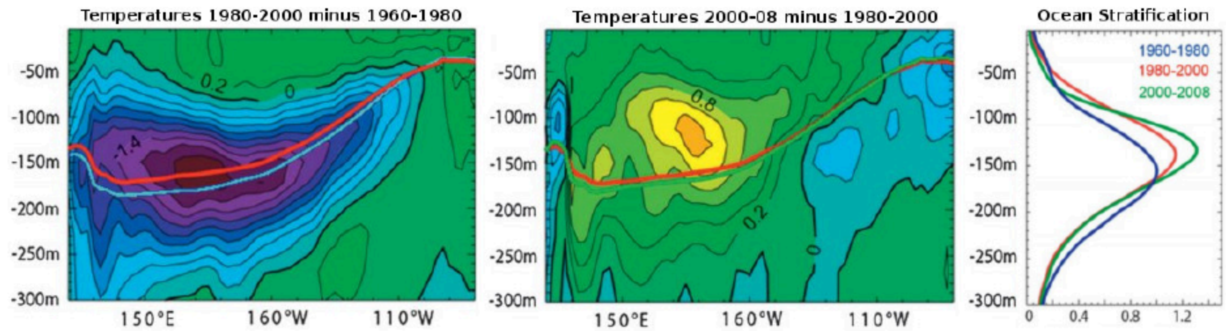

Figure 1. Observed decadal change of the equatorial Pacific ocean stratification (SODA reanalysis). Left and Middle, mean temperature differences between periods 1960-1980, 1980-2000 and 2000-2008, with overplot of mean thermocline depth over each period (20C isotherm, plain lines). Right, ocean stratification profile (Brunt-Vaisala frequency) over each period. Conventional shallow-water representations grasp weak thermocline depth changes but not the marked stratification changes,, thus a multi-baroclinic representation is preferred.

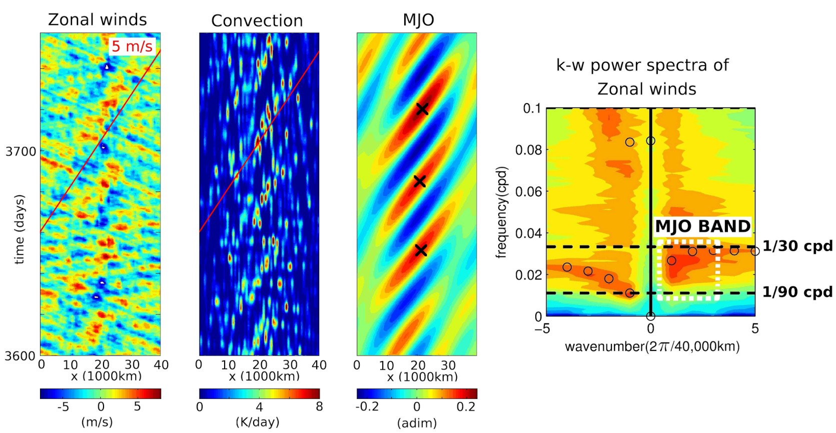

Figure 2. Solutions of a stochastic skeleton model for the MJO. Left, longitude-time hovmollers of equatorial zonal winds, convection and an MJO index as a function of zonal (i.e. longitudinal) position and time. MJO events propagate eastward at around 5 m.s−1 (red line) and form here a wavetrain of three strong consecutive events (black crosses). Right, power spectra of zonal winds, as a function of wavenumber and frequency. The stochastic model realistically reproduces maximal power in the MJO band (white dashed lines) as indicative of a strong and coherent MJO signal.

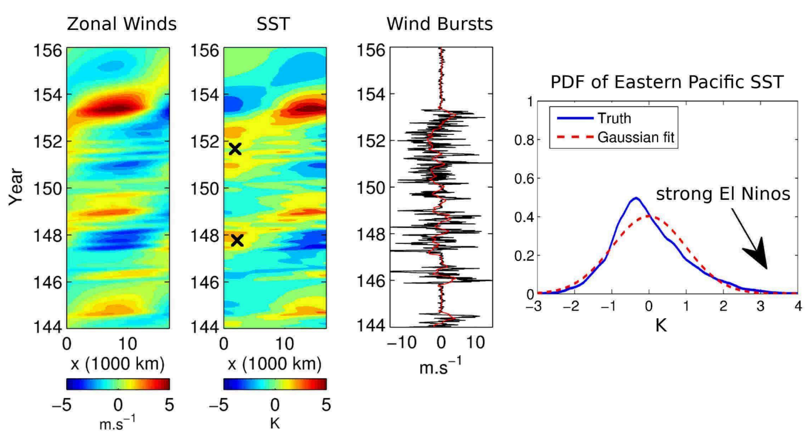

Figure 3. Solutions of an ENSO model with stochastic wind bursts. Left, longitude-time hovmollers of equatorial Pacific zonal winds, sea surface temperatures (SST), and plot of wind bursts amplitude. Wind bursts are random but usually favored during El Niño onset by warmer sea surface temperatures (black crosses). Right, probability density function of eastern Pacific SST. Due to wind bursts state-dependency the SST distribution is non-Gaussian with some rare strong El Niño events.

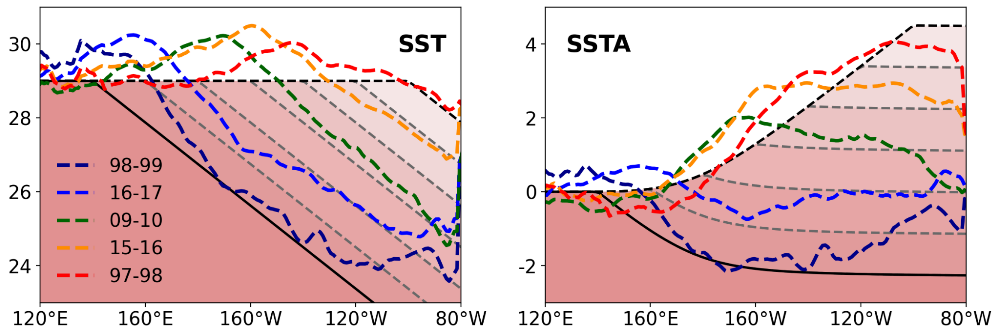

Figure 4. Patterns of sea surface temperature (SST) and their anomalies (SSTA) in the equatorial Pacific (averages 5N-5S). We compare observed El Niño and La Niña patterns (colors, DJF averages) to theoretical patterns obtained by shifting an idealized background circulation zonally in increments of 20 degrees (black and gray dashed lines). The spatial shifting explains the transition from La Niña broad cooling to central and eastern Pacific El Niño warming.

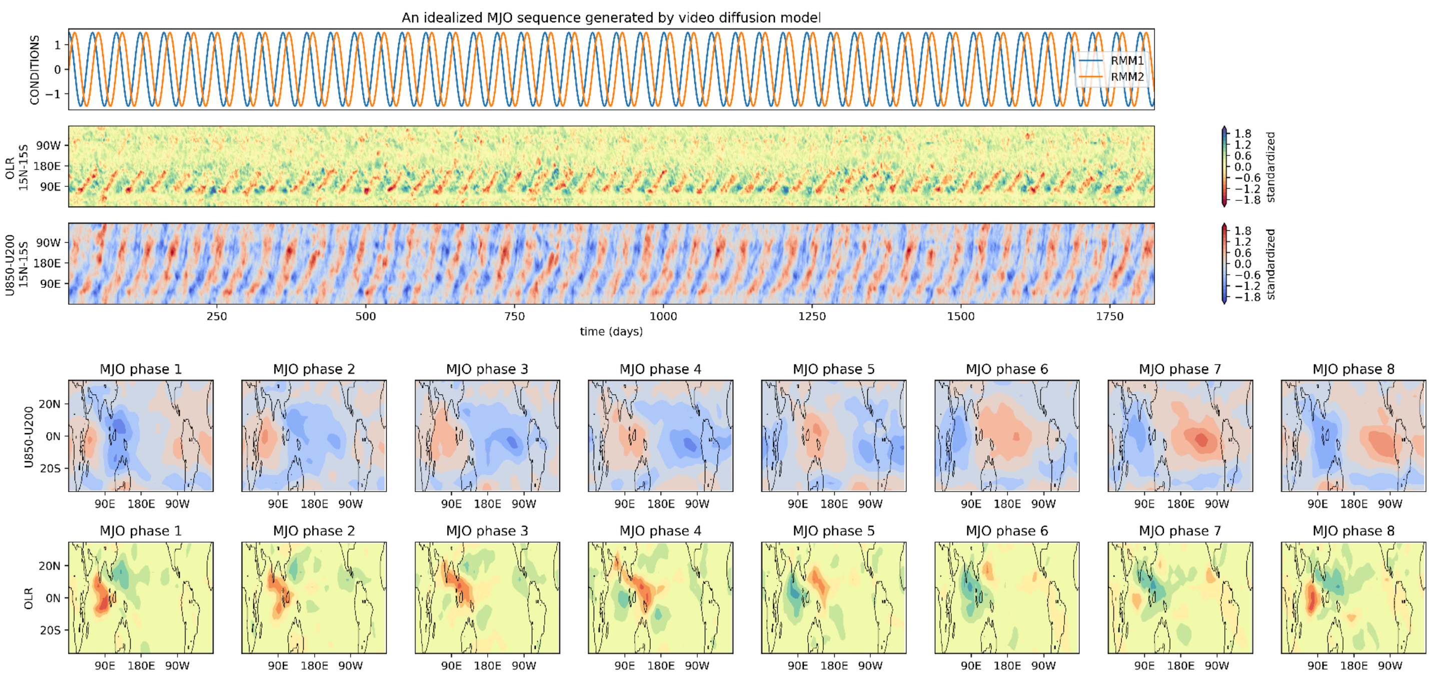

Figure 5. An idealized Madden-Julian Oscillation (MJO) sequence generated by a video diffusion model. The model was trained on ERA5 reanalysis and is here conditioned by the MJO RMM index. The model can generate idealized yet realistic MJO sequences (e.g. a perpetual MJO with constant period), which helps bridge theory and observations.