# Jet stream variability and predictability

G. Riviere LMD-ENS

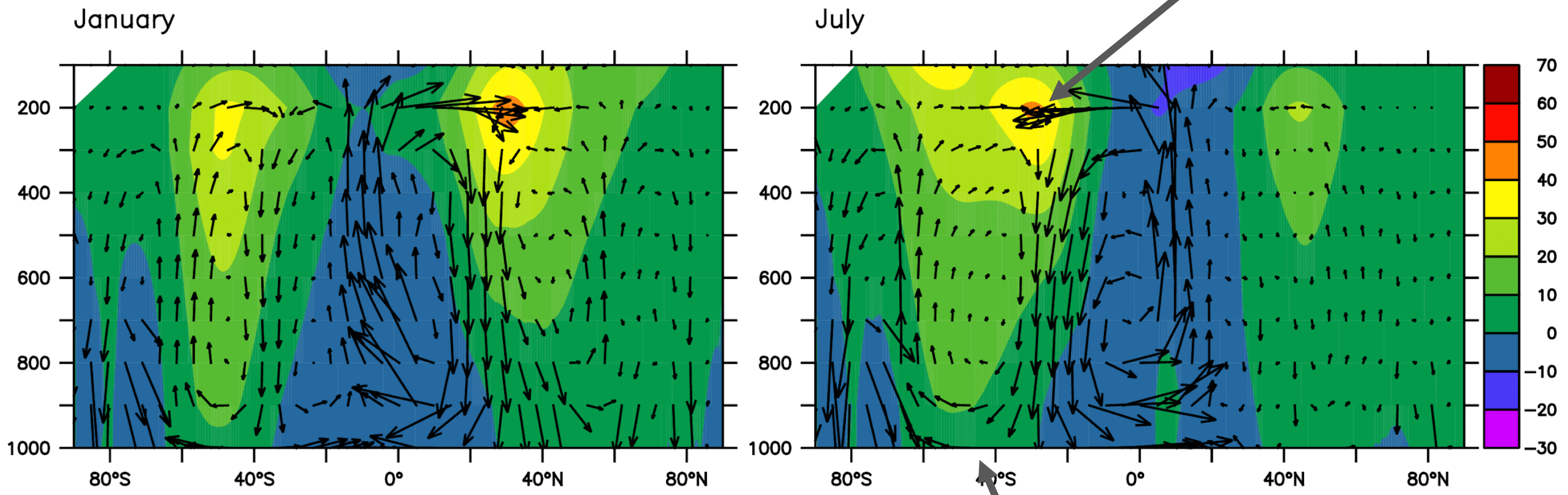
Coll : A. Hermoso[1], S. Schemm[1], M. Saint-Lu[2], S. Fromang[3]
[1] ETH, Zurich
[2] LMD
[3] LSCE

GDR theorie-climat, 6 juin 2023

# Outline

1. Definition of the different jets: Subtropical vs eddy-driven
2. Concepts of jet variability: EOFs, regimes, ...
3. Trends and future evolution of jets: global vs local pictures
4. Subseasonal predictability of North Atlantic jet

# Subtropical vs eddy-driven jets

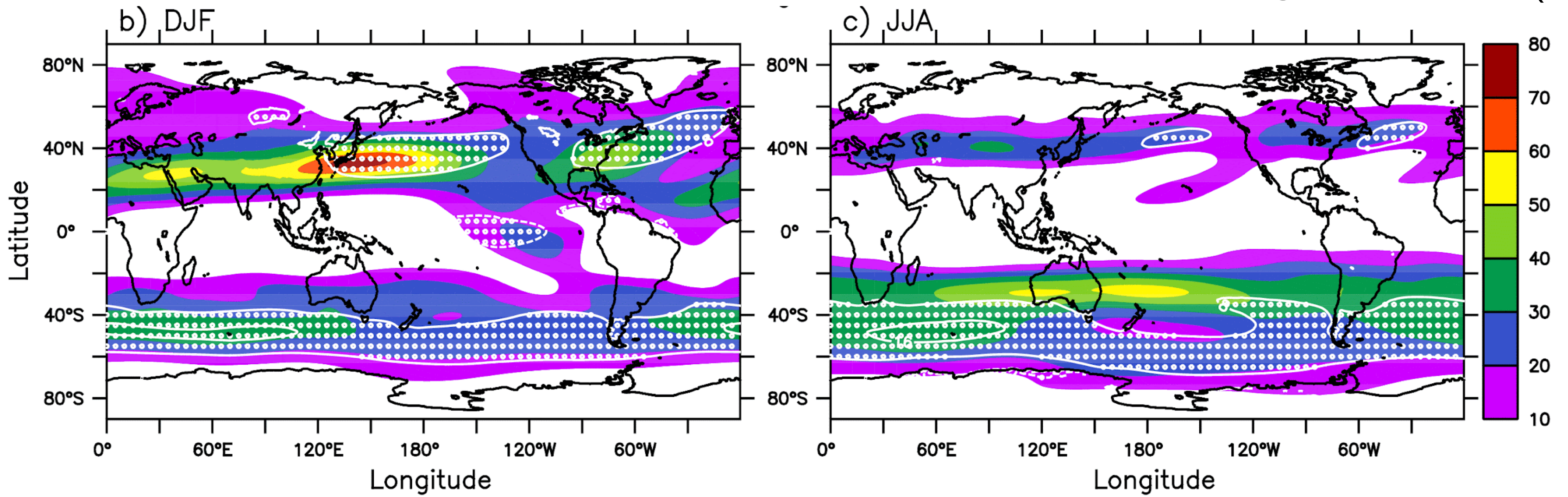



Subtropical jet at the edge of Hadley Cell

Eddy-driven jet in the middle of the Ferrel Cell

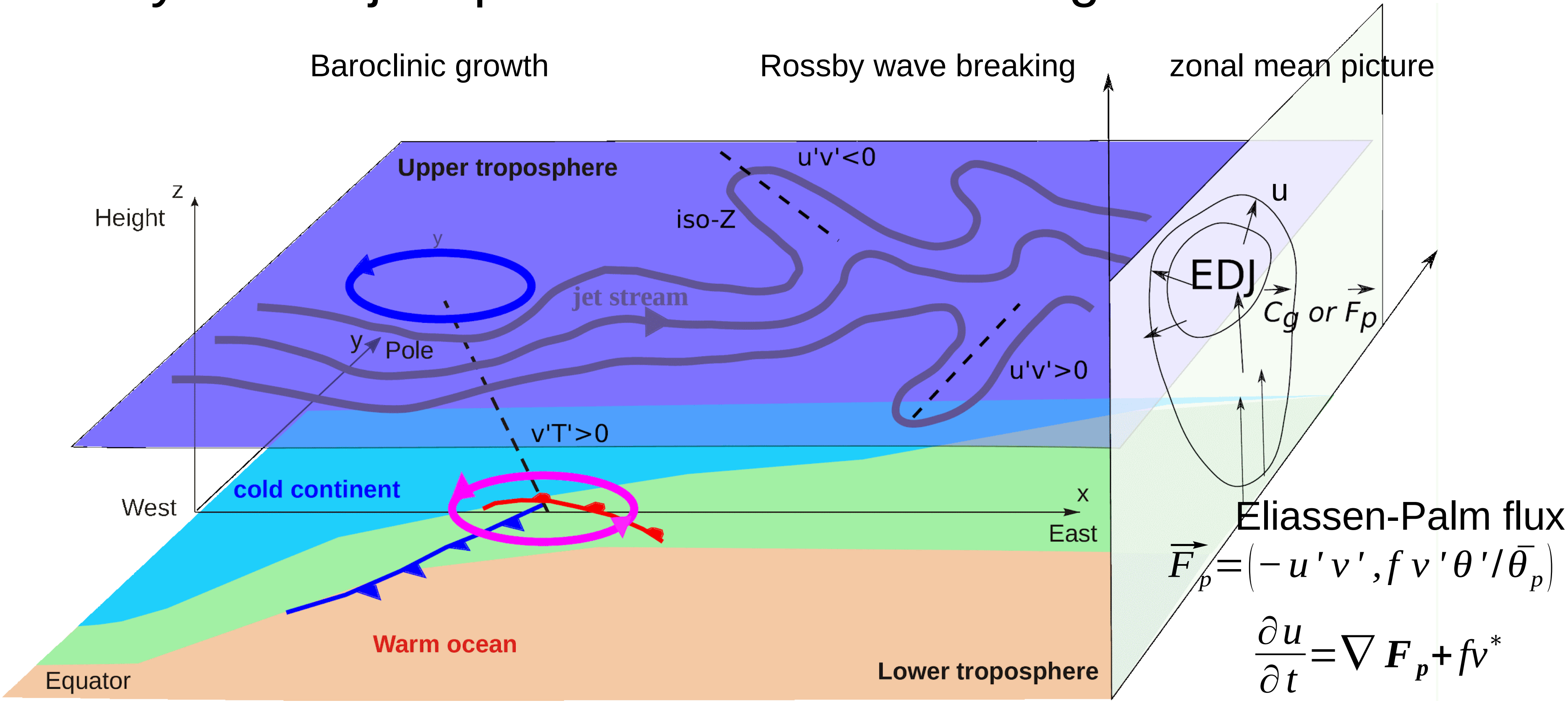
# Subtropical vs eddy-driven jets

U@250mb (shadings)
U@850mb >8 m/s (white)




- South Pacific: the two jets are well separated
- North Pacific: more merged jets
- North Atlantic: eddy-driven jet well separated from subtropical African jet

# Eddy-driven jets processes : the basic ingredient




$$\vec{F}_p = \left(-u'v', f v'\theta'/\bar{\theta}_p\right)$$

$$\frac{\partial u}{\partial t} = \nabla \boldsymbol{F}_p + f v^*$$

Convergence of momentum flux at the same latitude as the stirring region !

# Chain of reasonings to explain jets variability and trends

Observed variability / trend of zonal winds

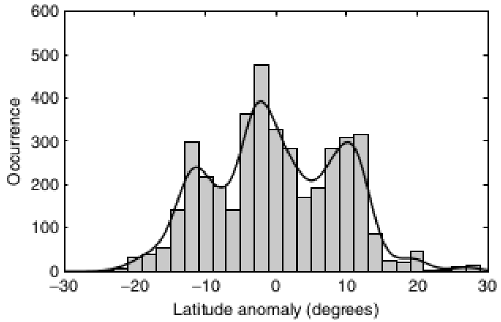
Observed variability / trend of eddy momentum flux convergence or wave breaking

Observed variability / trend of baroclinic growth (change in latitude, intensity, wavenumbers)

Observed variability / trend of thermal contrasts

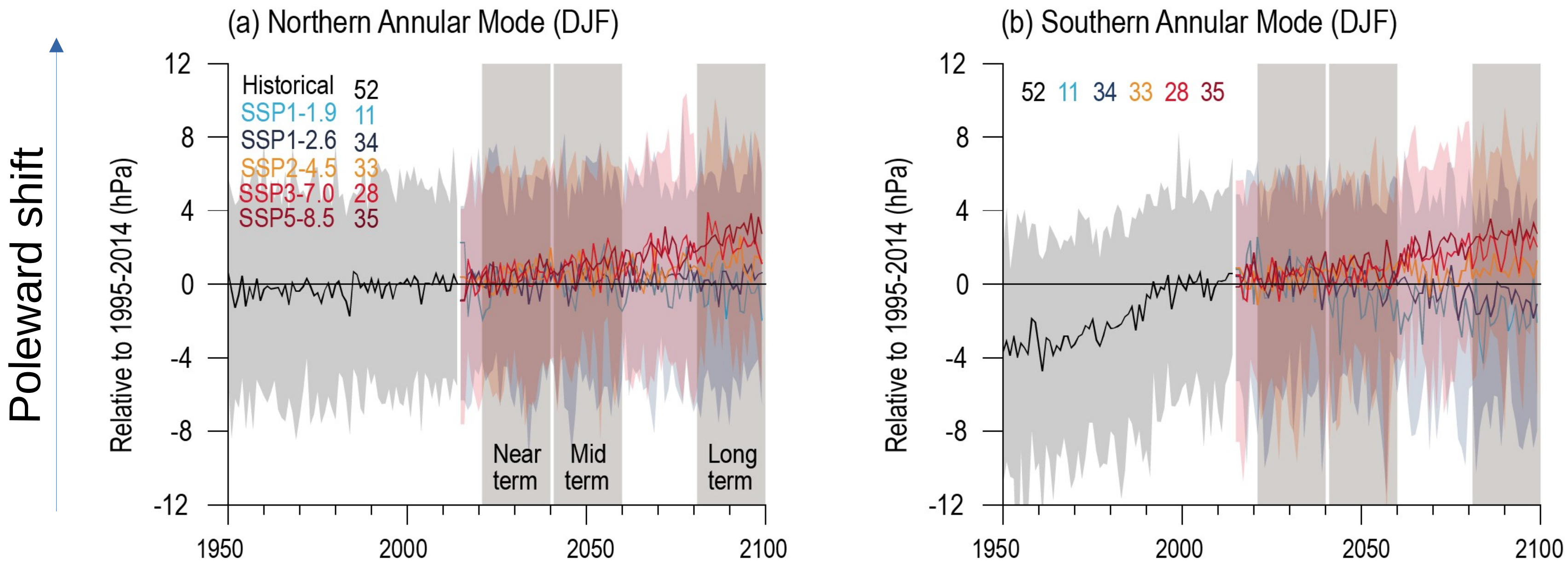
# Concepts of jets variability

- **Teleconnections** : Spatial correlation maps (Wallace and Gutzler, 81) NAO /  PNA
- **Leadings modes of variability / EOFs**
    Annular modes (EOF1 Z hemisphere ; Thompson and Wallace, 2000)
    NAO (EOF1 geopotential North Atlantic ; Barnston and Livezey, 1987)
- **Weather regimes** :
    4 Wrs in the North Atlantic (Vautard, 1990)
- **Latitudinal variations of eddy-driven jets** :
    zonal mean zonal wind distributions (Woollings et al., 2010)




U anom @700-850mb, DJF, daily, Atlantic

# The zonal mean picture of the future evolution of the jets

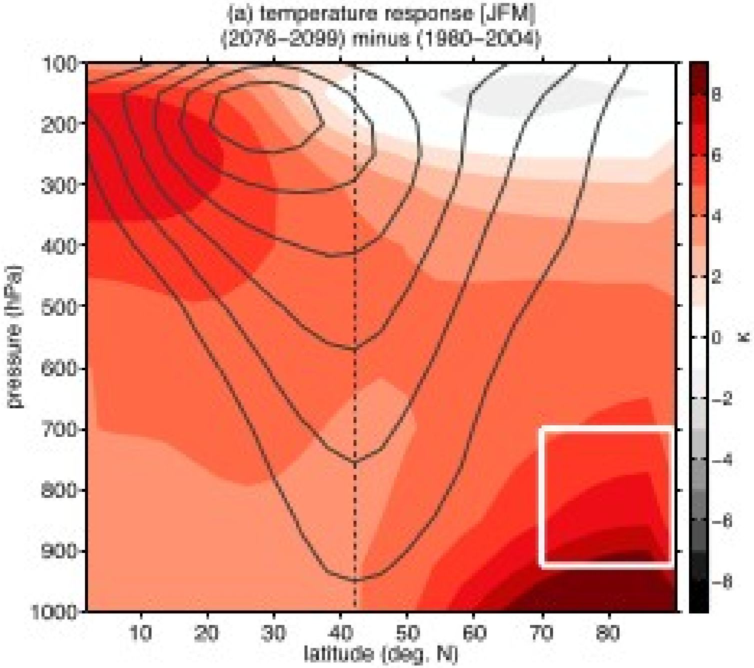



Source : AR6 WG1, chap. 4

Poleward shift only visible for high and very high GHG scenarios

In the SH, 2 effects : GHG and ozone

# The « tug of war » between upper- and lower-level changes in thermal contrasts

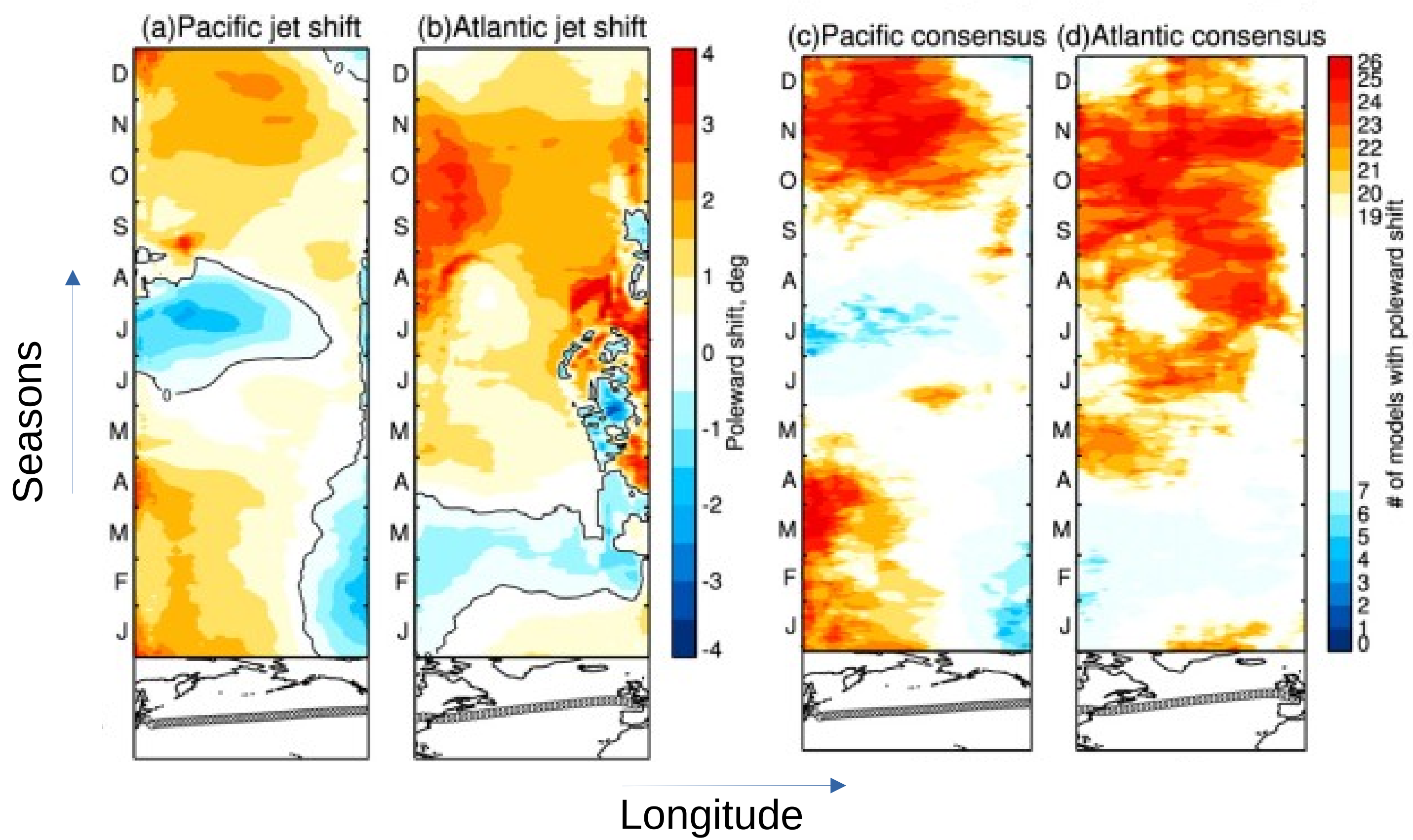



CMIP5, RCP8.5

Barnes and Polvani (2015)

Increase in upper-level baroclinicity leads to poleward shift and decrease in lower-level baroclinicity leads to equatorward shift. Each separate effect is clear but no clear consensus on mechanisms !

# From the global to the more regional perspective



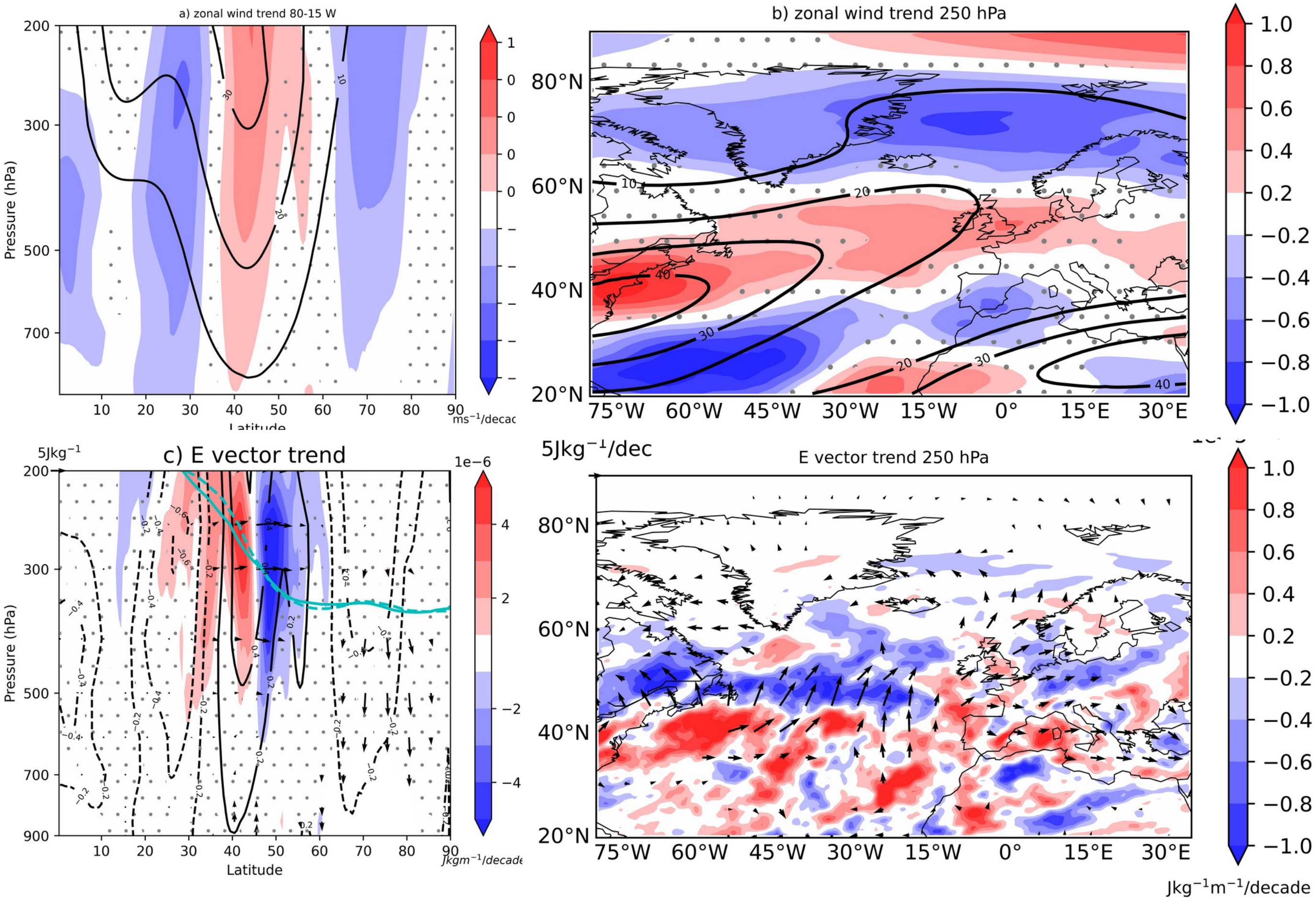

Simpson et al. (2014)

No consensus in the wintertime North Atlantic jet !

# Part 1 : Trends in the North Atlantic jet and potential mechanisms

# The North Atlantic jet trends in ERA5

Hermoso et al. (2023, to be submitted)



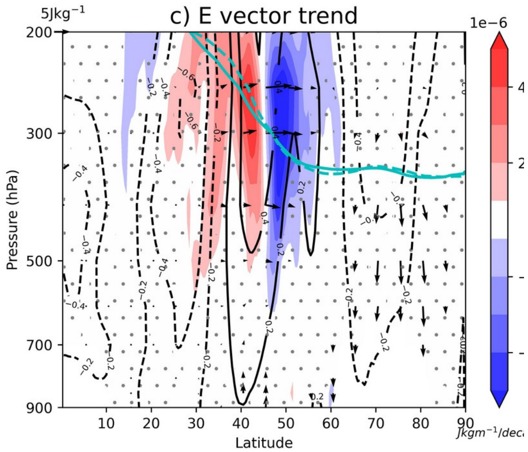

Zonal wind

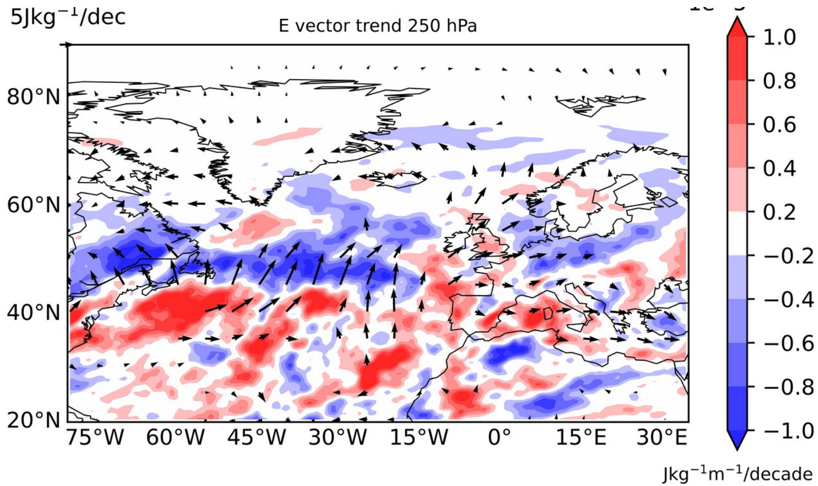
See Simmons (2022) for further details on ERA5 trends

Momentum deposit

$$E=\left(\frac{1}{2}\left(v'^2-u'^2\right),-u'v',\frac{f}{\bar{\theta}_p}v'\theta'\right)$$

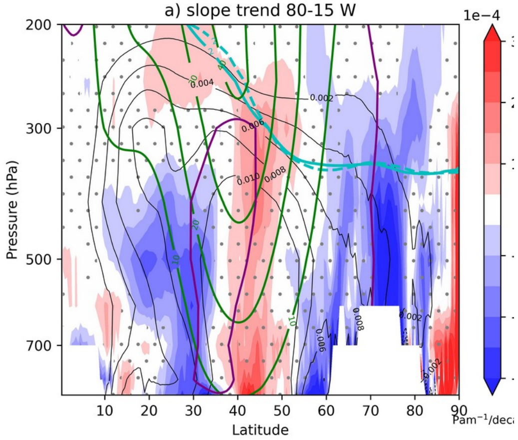
# The North Atlantic jet trends in ERA5

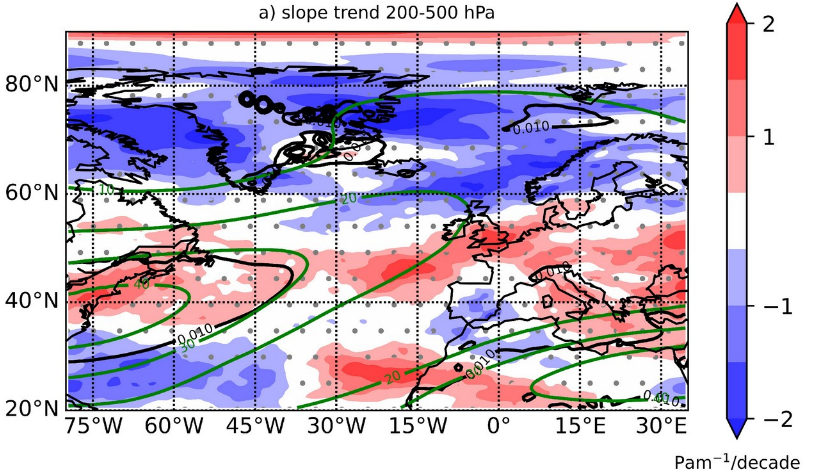



Momentum deposit

$$E=\left(\frac{1}{2}\left(v'^2-u'^2\right),-u'v',\frac{f}{\overline{\theta}_p}v'\theta'\right)$$

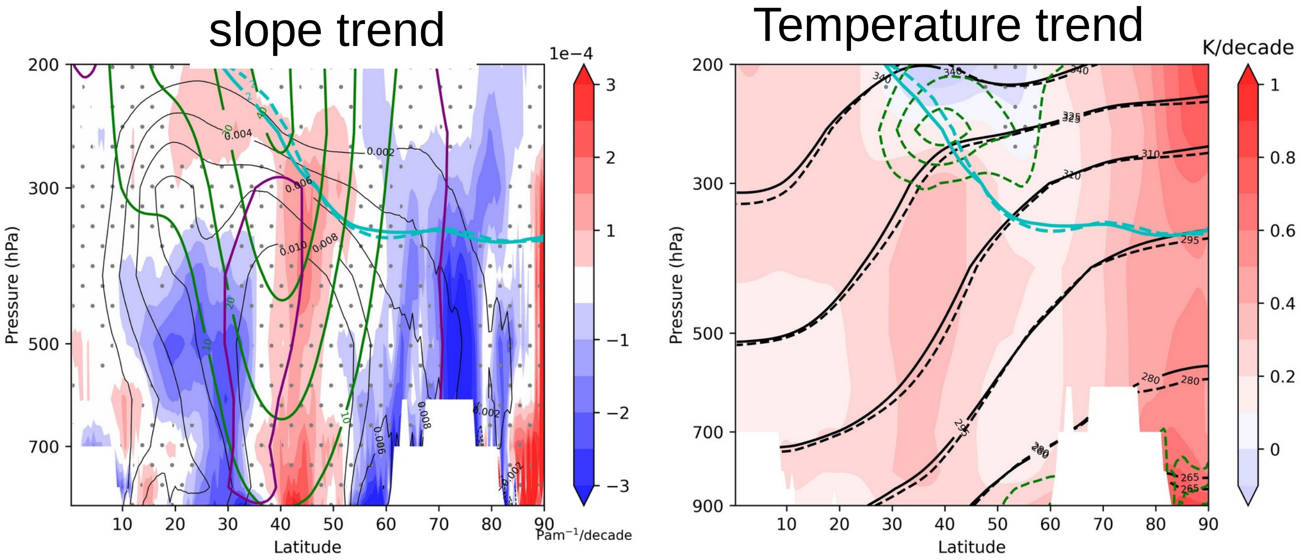



Baroclinicity measure

$$slope=\frac{d\theta/dy}{d\theta/dp}$$

# The North Atlantic jet trends in ERA5

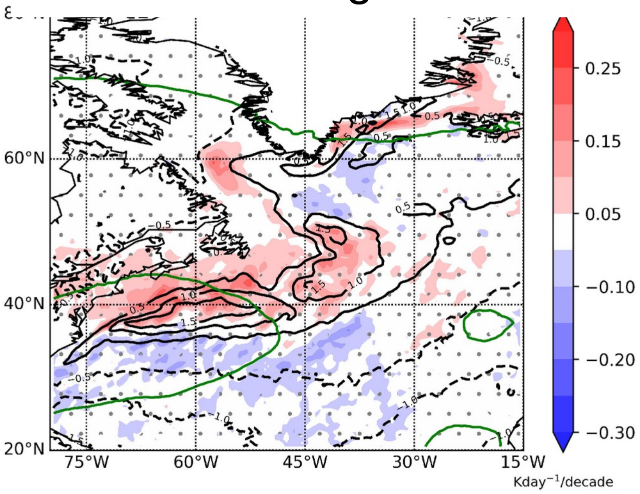



The temperature trend has a barotropic structure → horizontal gradient of the temperature trend is affecting more the baroclinicity

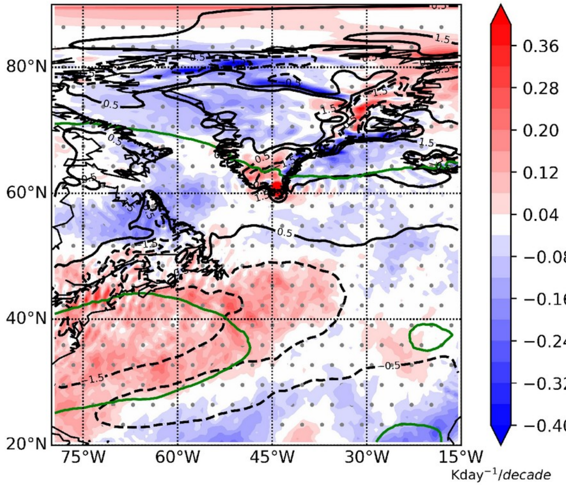
# The North Atlantic jet trends in ERA5

300-850 hPa average

Diabatic heating trend



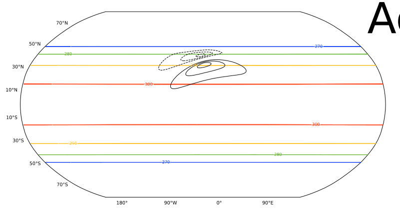

Temperature advection trend




- more heating over the Gulf Stream region
- less cold air advection (likely due to less land-sea thermal contrasts)

# ICON aquaplanet experiments

- 5-year simulations in perpetual winter configuration
- Horizontal resolution of approximately 80 km and 70 vertical levels
- SST baseline distribution with a superimposed SST front with an amplitude of 10 K and located at 30W and different latitudinal positions
- Two simulations:
  - Control: baseline SST and front
  - Warming: baseline SST uniformly warmed by 4 K and front

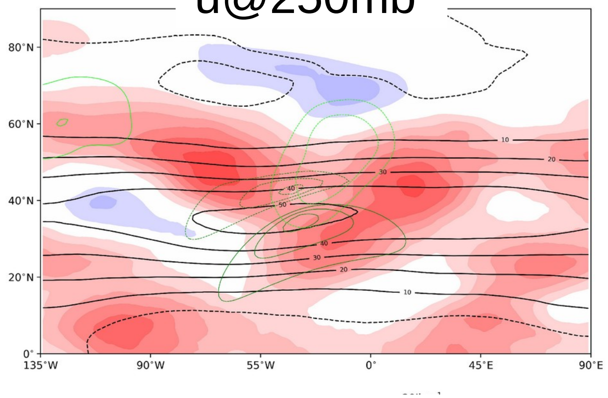



Aquaplanet setup

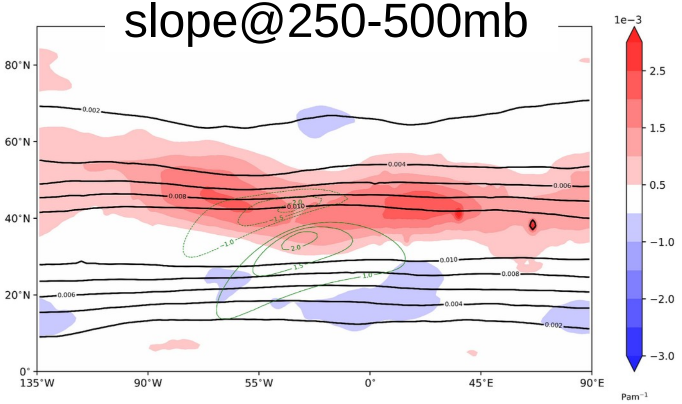
# ICON aquaplanet runs vs ERA5 trends

ICON runs (+4K-ctrl)

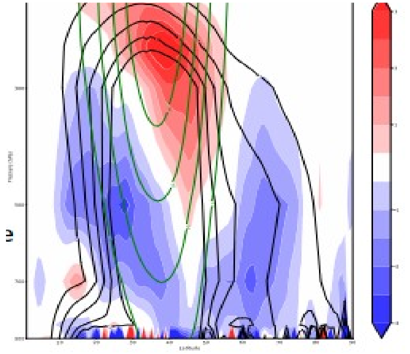
u@250mb




slope@250-500mb



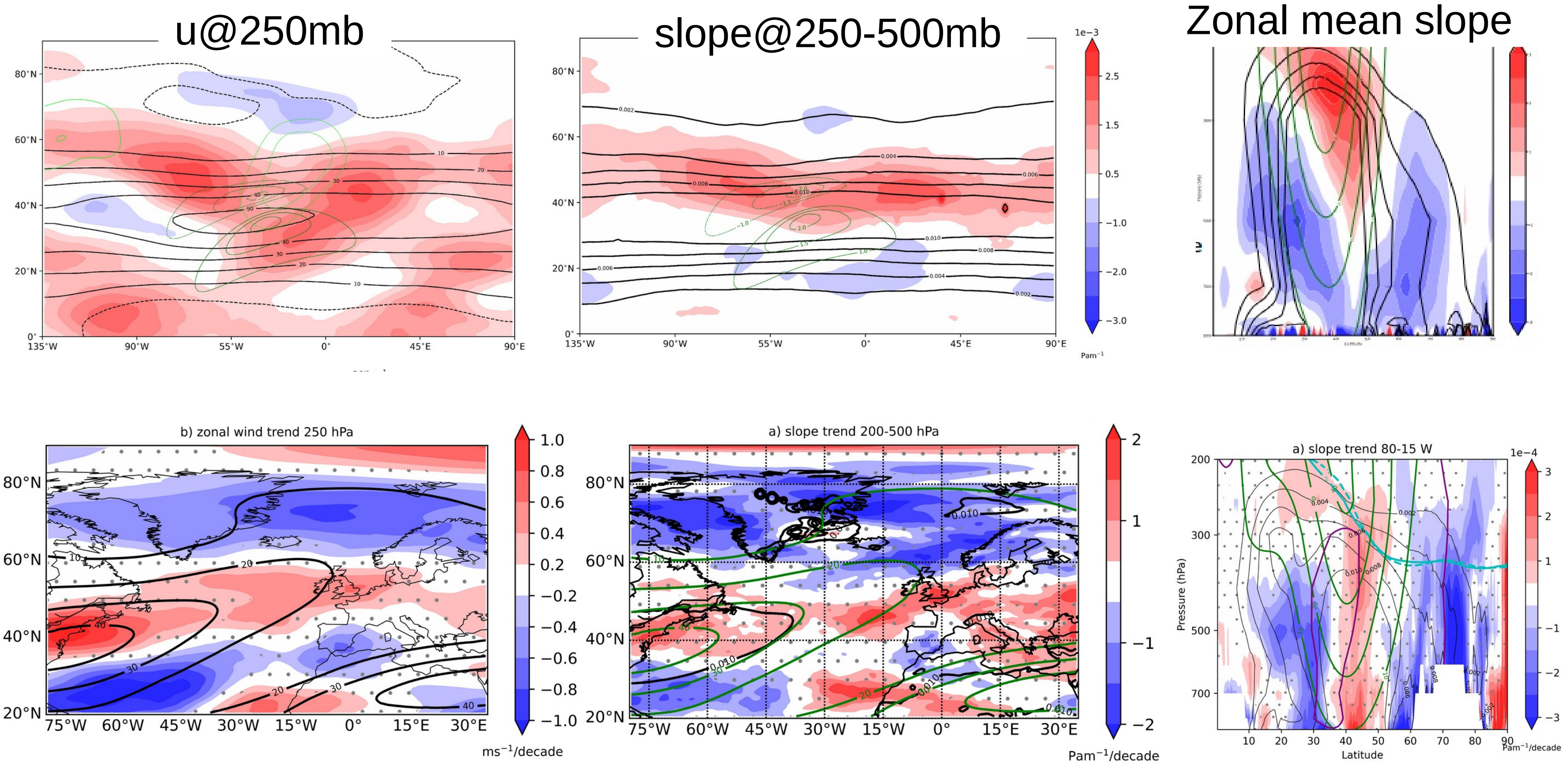

Zonal mean slope



# ICON aquaplanet runs vs ERA5 trends

ICON runs (+4K-ctrl)

ERA5 trend



# Conclusions on NA jet trends / mechanisms

- The North Atlantic jet stream has intensified in winter and roughly remained in place during the last decades
- Diabatic heating has intensified over the Gulf Stream. As a result, baroclinicity and eddy momentum convergence have increased around the jet core.
- The main physical mechanisms can be reproduced with idealized aquaplanet experiments. However, the jet response exhibits a large sensitivity to the position of the SST anomaly

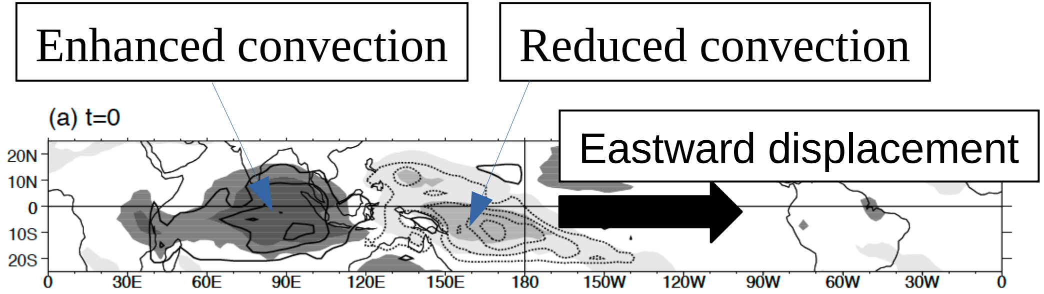
Hermoso et al. (2023, to be submitted)

# Part 2 : Subseasonal predictability of the North Atlantic jet : the MJO-NAO teleconnexion

# *The Madden Julian Oscillation (MJO)*

*(Madden & Julian 1971, 1972)*

**Dominant mode of intraseasonal variability in the tropics**




*Outward Longwave Radiation (OLR) – from Matthew et al. (2004)*

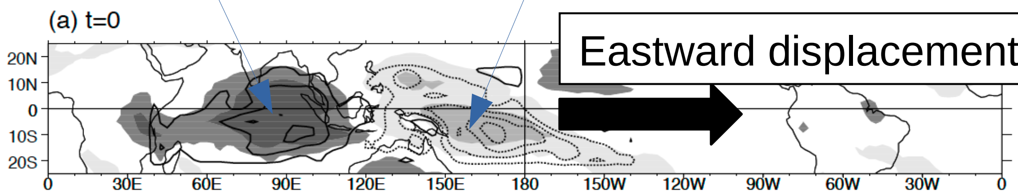
**Main properties**

- Coupled enhanced/suppressed convection dipole propagating eastward ($v_{prop}$~5 m/s)
- Typical period ~ 40-50 days
- Appear in Indian Ocean – weakens in eastern Pacific
- Eight phases typically distinguished

# *The Madden Julian Oscillation (MJO)*

*(Madden & Julian 1971, 1972)*

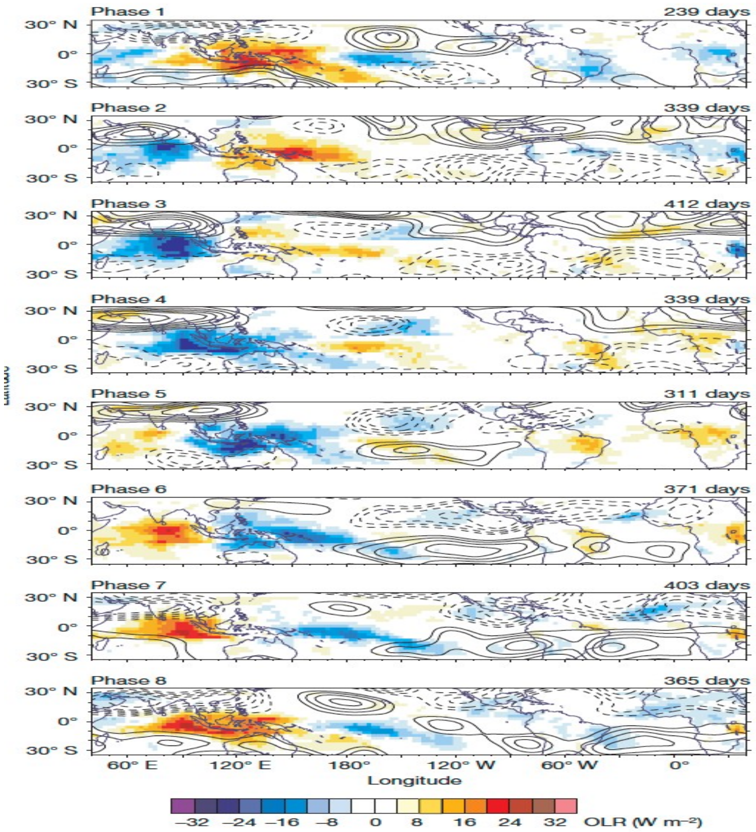
**Dominant mode of intraseasonal variability in the tropics**




*Outward Longwave Radiation (OLR) – from Matthew et al. (2004)*

**Main properties**

- Coupled enhanced/suppressed convection dipole propagating eastward ($v_{prop}$~5 m/s)
- Typical period ~ 40-50 days
- Appear in Indian Ocean – weakens in eastern Pacific
- Eight phases typically distinguished



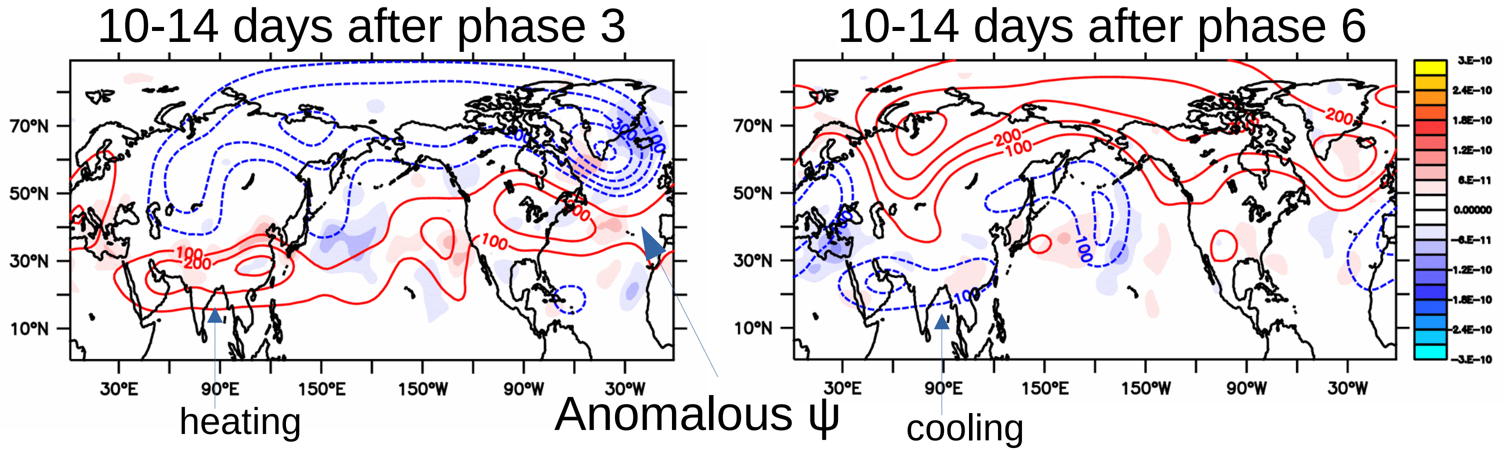

Cassou (2008)

# The MJO-NAO teleconnexion

Project : ROADMAP (JPI-Climate), Collaborations : M. Saint-Lu, S. Fromang

Starting point: evidence of MJO impact on the NAO in observational datasets (Cassou, 2008 ; Lin et al. 2008).

ERA5 (1979-2016)




Our objective / approach: better understanding of the involved processes (troposphere vs stratosphere) using idealized GCM

Method: use of the dry version of the atmospheric model DYNAMICO. In the present case, ~200 km horiz res° and 14 vertical levels in the troposphere

→ Model steady forcing such that the model climatology is close to that observed during winter (ERA5 reanalysis taken as a reference)

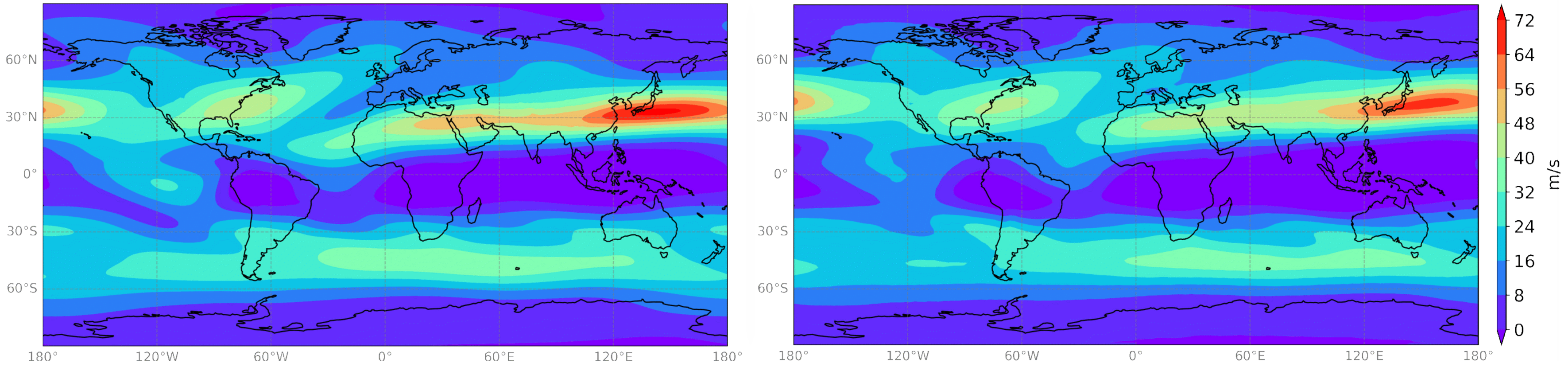
→ iterative process consisting of running the model for 2 years for each iteration (Chang, 2006) to find the appropriate thermal forcing (relaxation in temperature)

→ 40 years long control run with steady forcing

$$\frac{d\theta(\lambda,\varphi,p)}{dt} = -\frac{\theta(\lambda,\varphi,p) - \theta_{eq}^{n}(\varphi,p)}{\tau(\varphi,p)}$$

DJF ERA5 reanalysis (1979-2018)

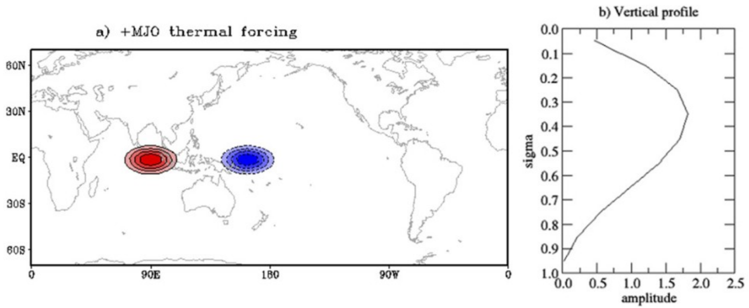
Control run : 40 years of perpetual winter

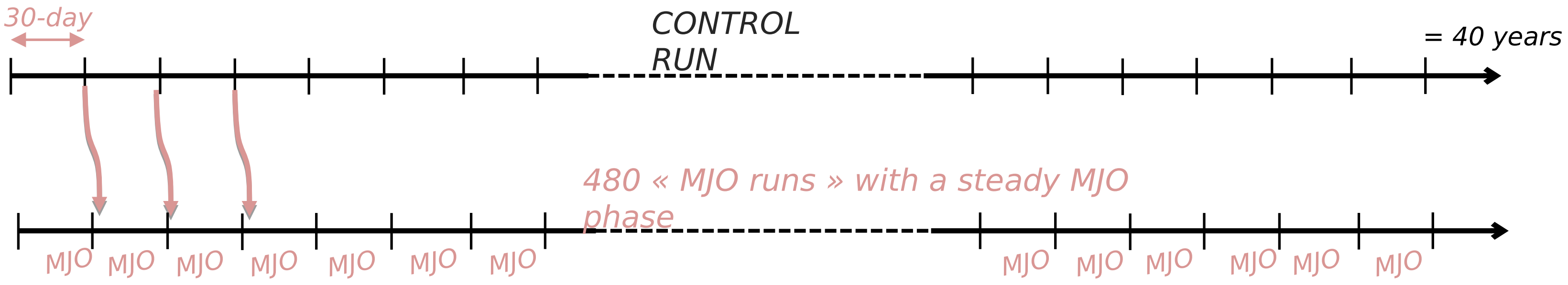


Sensitivity experiments by adding an MJO-type forcing with a fixed phase

→ Analytically prescribed MJO forcing in the temperature tendency

→ Average over 480 runs of 30 days duration (Similar to Zheng and Chang, 2019).

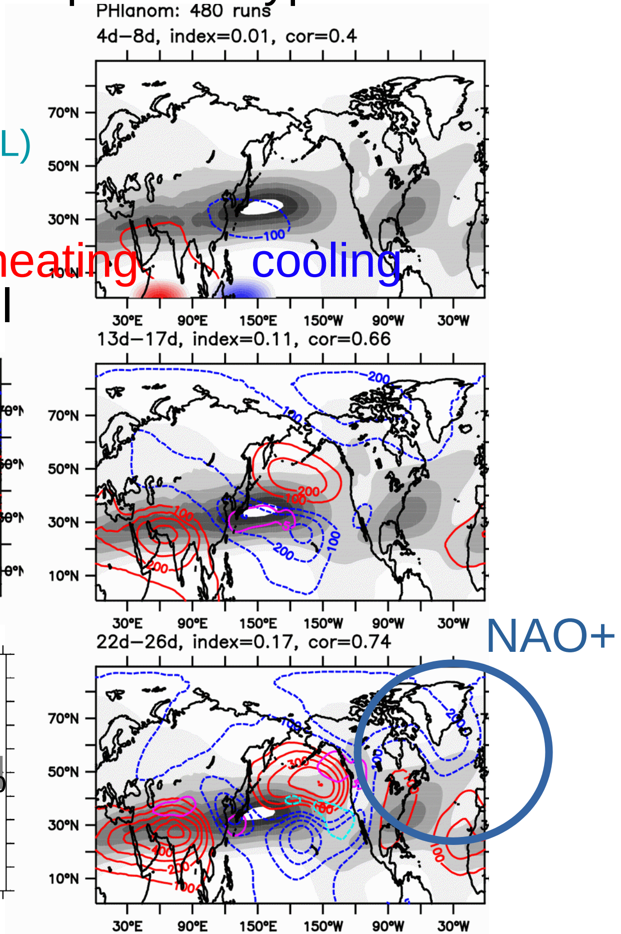


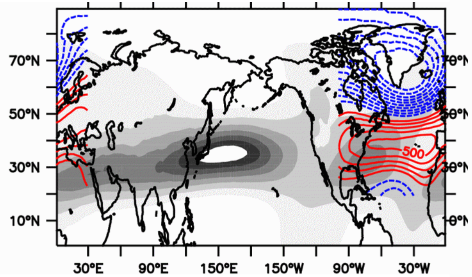
# Phase 3

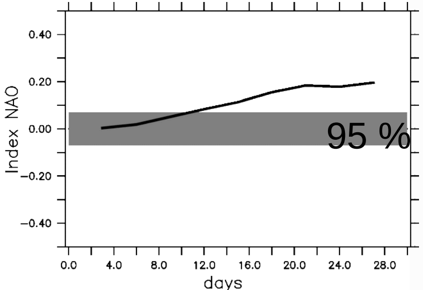
## MJO phase 3 type / 480 runs

Shadings : U@300mb
Contours : anomalous streamfunction (MJO-CTL)




## NAO in the model



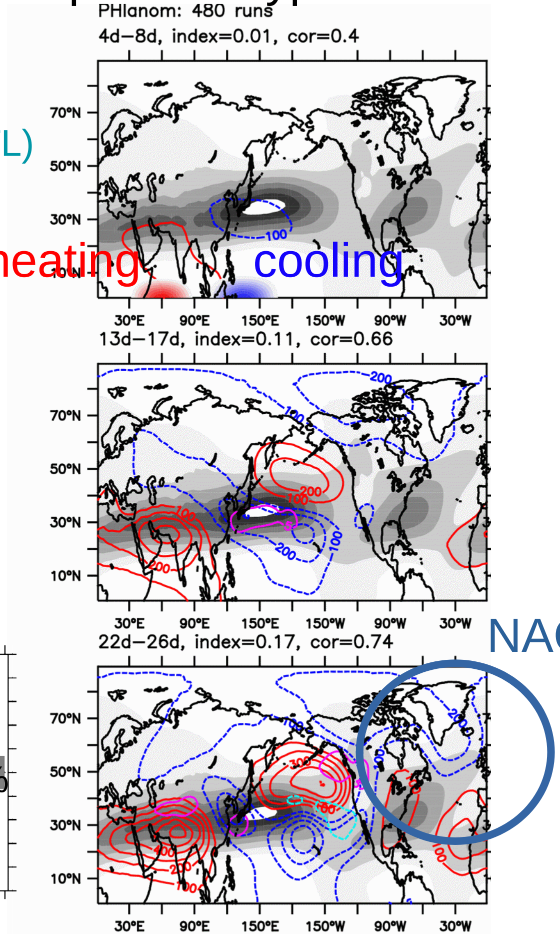



# Phase 3

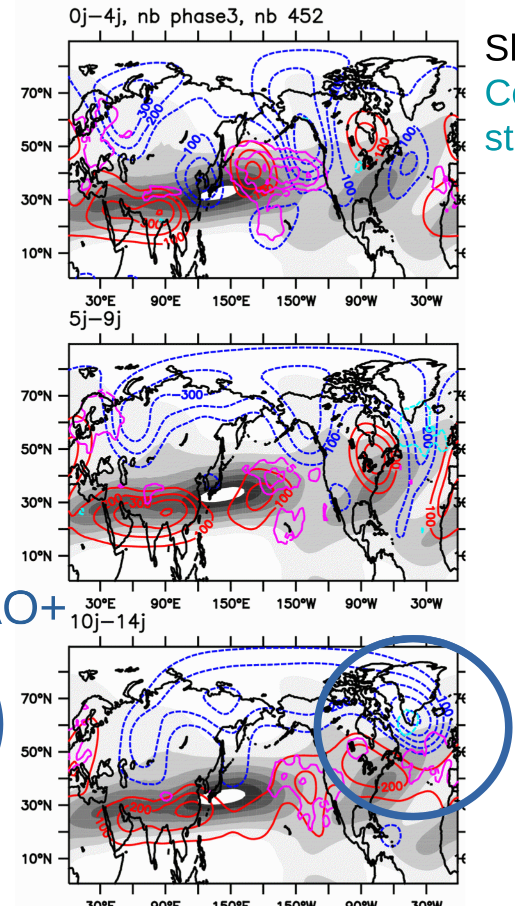
MJO phase 3 type / 480 runs

ERA5 (1979-2016) / 452 days

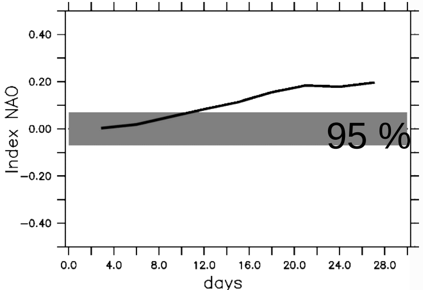
Shadings : U@300mb
Contours : anomalous streamfunction (MJO-CTL)

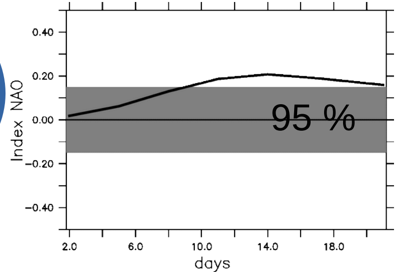



NAO+




Shadings : U@300mb
Contours : anomalous streamfunction (MJO-clim)

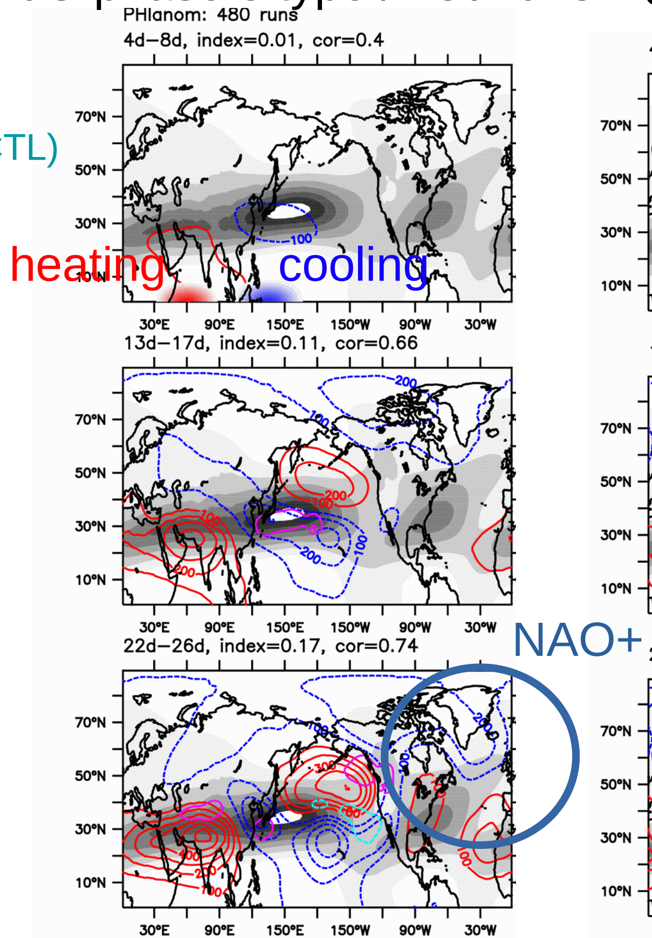


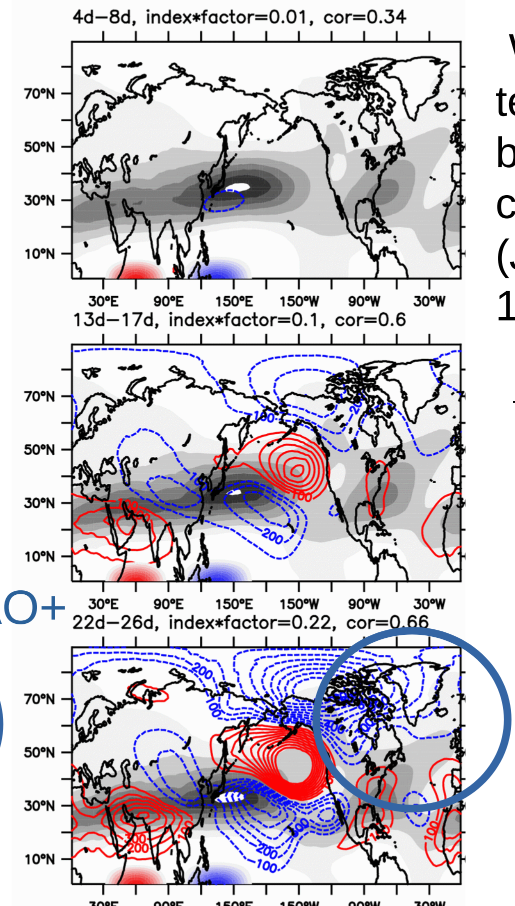
# Phase 3

Shadings : U@300mb
Contours : anomalous streamfunction (MJO-CTL)

MJO phase 3 type / 480 runs




Stationary wave model (1 run)



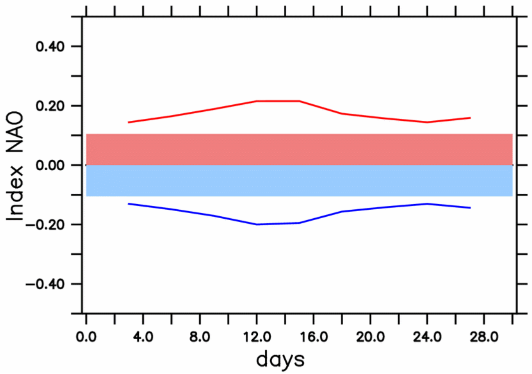

We suppress the tendency of the background climatological flow (Jin and Hoskins, 1995) :

$$\frac{\partial \Psi}{\partial t} = N(\Psi) - N(\bar{\Psi})$$

Climatology

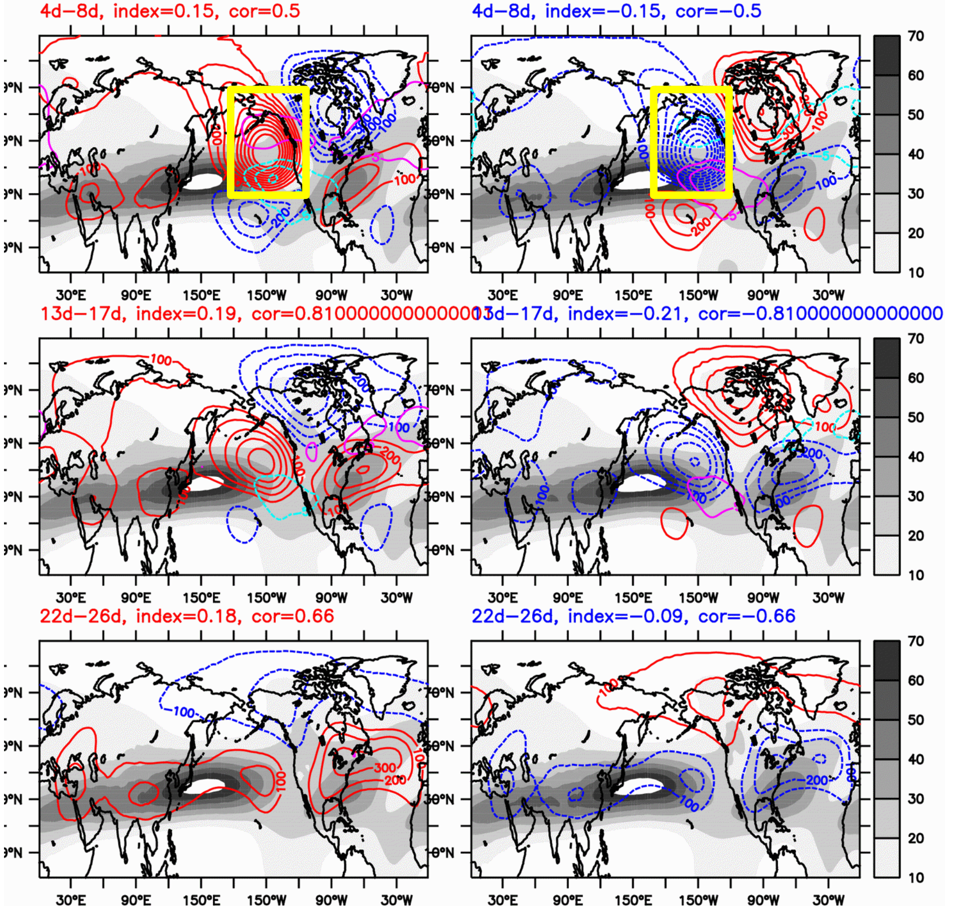
# Separation of the 480 ctl runs into 2 sub-groups depending on the North Pacific flow at t=0

The large-scale ridge in phase 3 is potentially helping to force the NAO+ (Marie Drouard (2013)'s PhD)



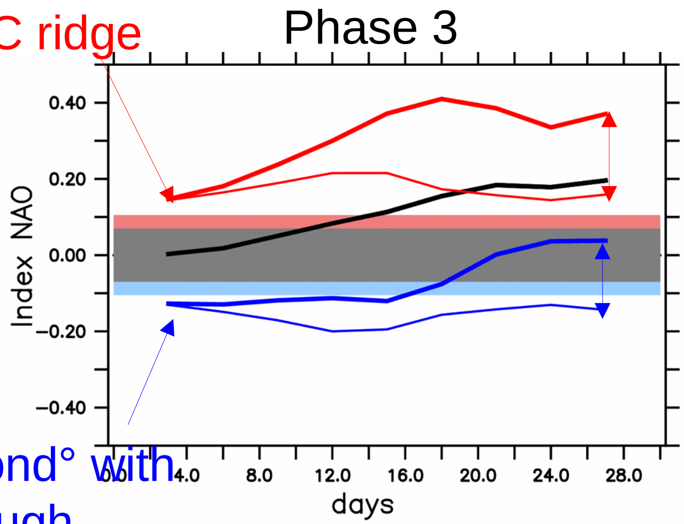

Pacific ridge (228 runs)

Pacific trough (252 runs)

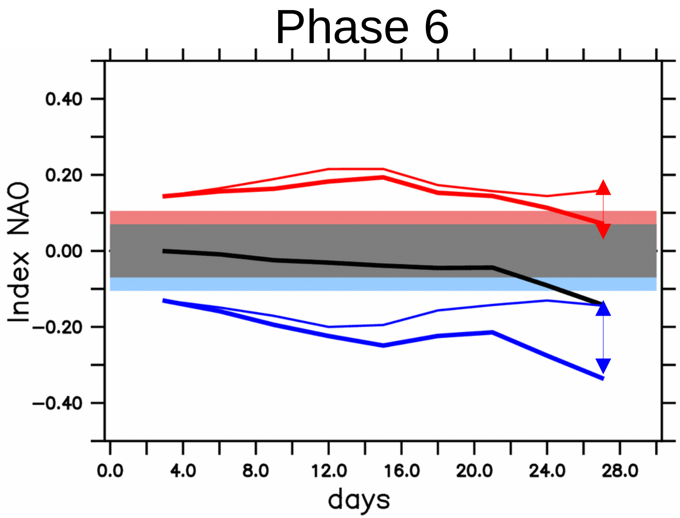


# Modulation of the NAO-MJO teleconnection by the eastern North Pacific flow

Initial cond° with PAC ridge




Initial cond° with PAC trough




The effect of phase 3 (phase 6) is more pronounced in presence of a Pacific ridge (trough) at the initial time !

# Conclusions on MJO-NAO teleconnexion

- The MJO-NAO teleconnexion can be reproduced in dry GCM nonlinear simulations but also in stationary wave linear model at zero order (no need of baroclinic eddies)
- The MJO-NAO teleconnexion is modulated by the North Pacific flow: the pre-existence of a Pacific ridge (trough) helps to reinforce phase3-NAO+ (phase6-NAO-). The stationary wave model is not reproducing such an effect --> baroclinic eddies are needed !

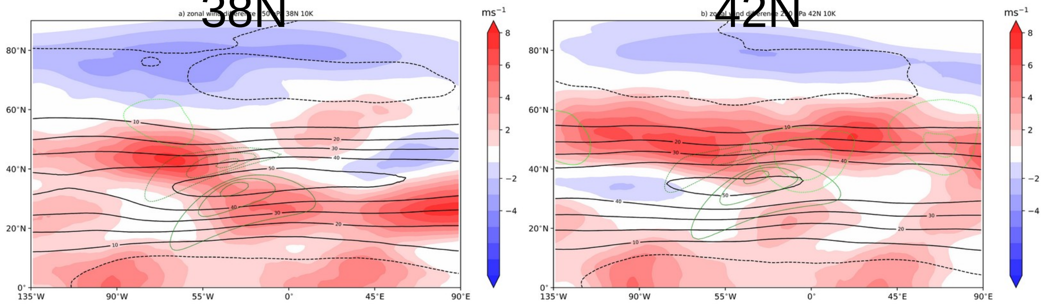
Saint Lu et al. (2023, in preparation)

# Additional slides

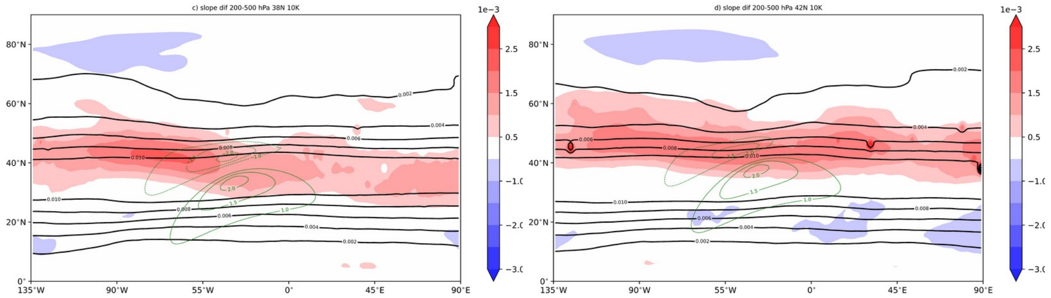
# Sensitivity to SST front latitude

38N 42N

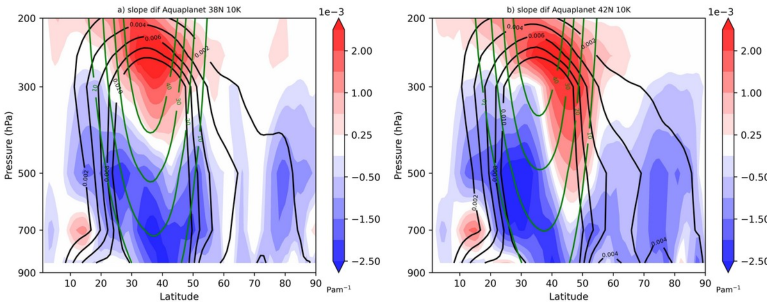
u@250mb




slope@250-500mb




Zonal mean slope



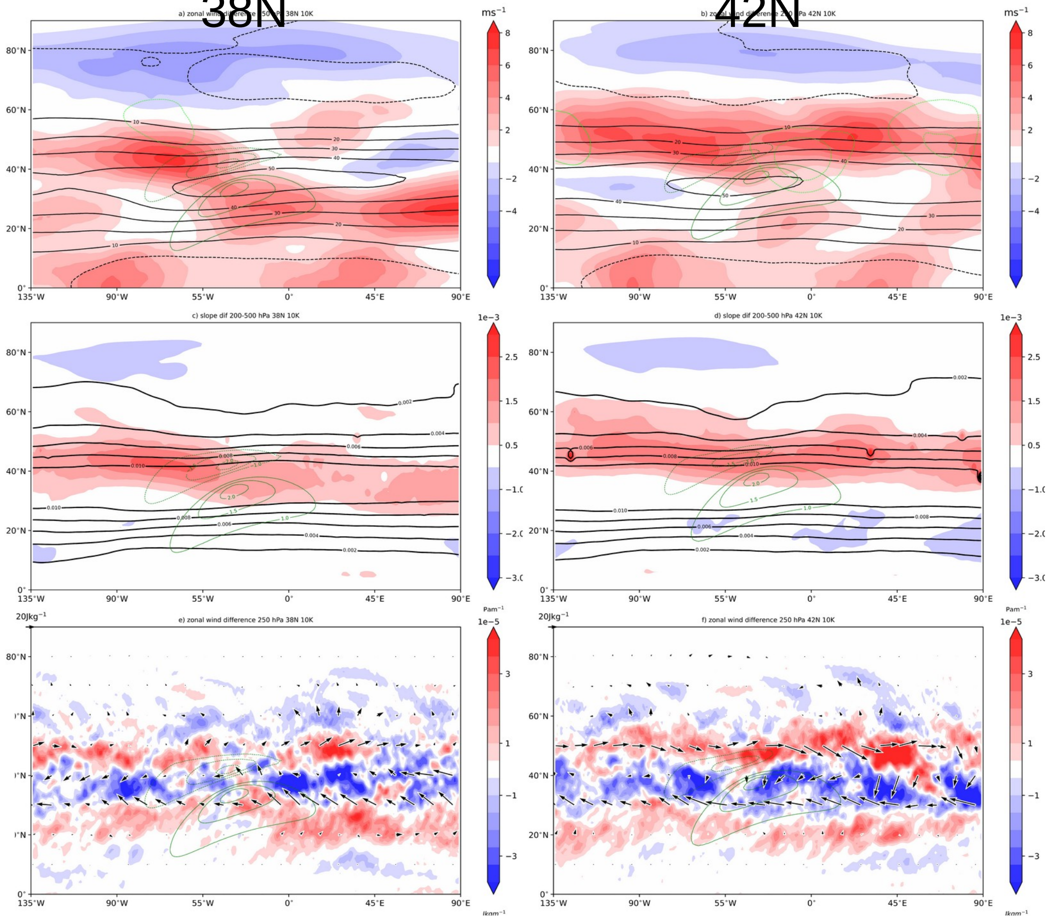
# Sensitivity to SST front latitude

38N 42N

u@250mb

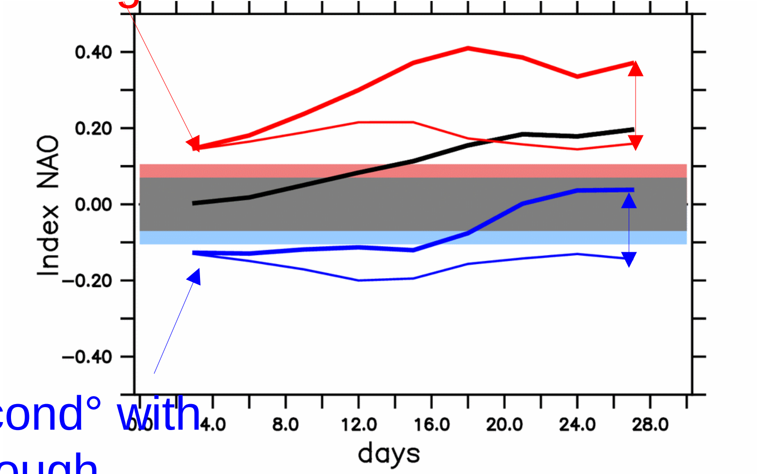
slope@250-500mb

E-vector@250mb



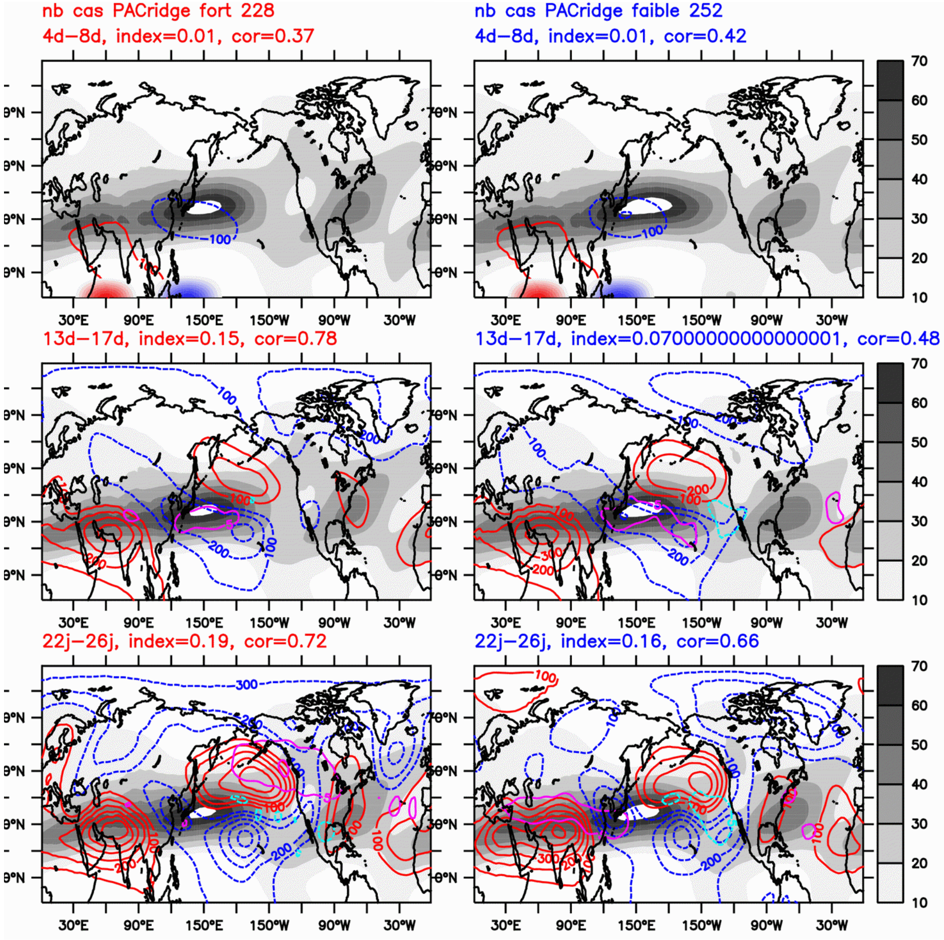
# Phase 3 impact as function of a pre-existing Pacific ridge/trough

Initial cond° with PAC ridge



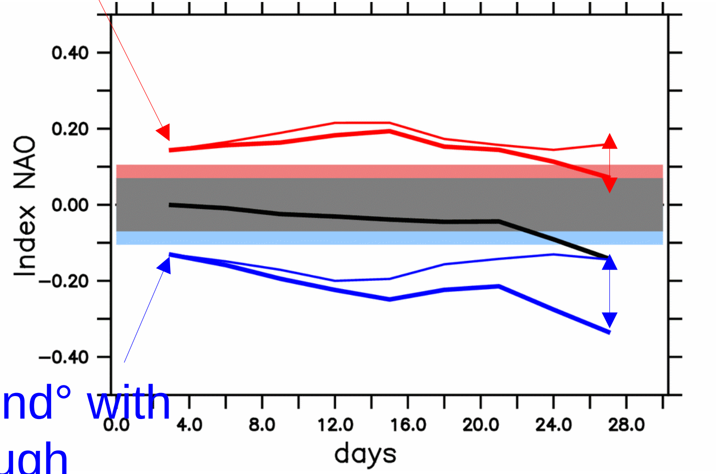

Initial cond° with PAC trough

Anomalous streamfunction with respect to control runs



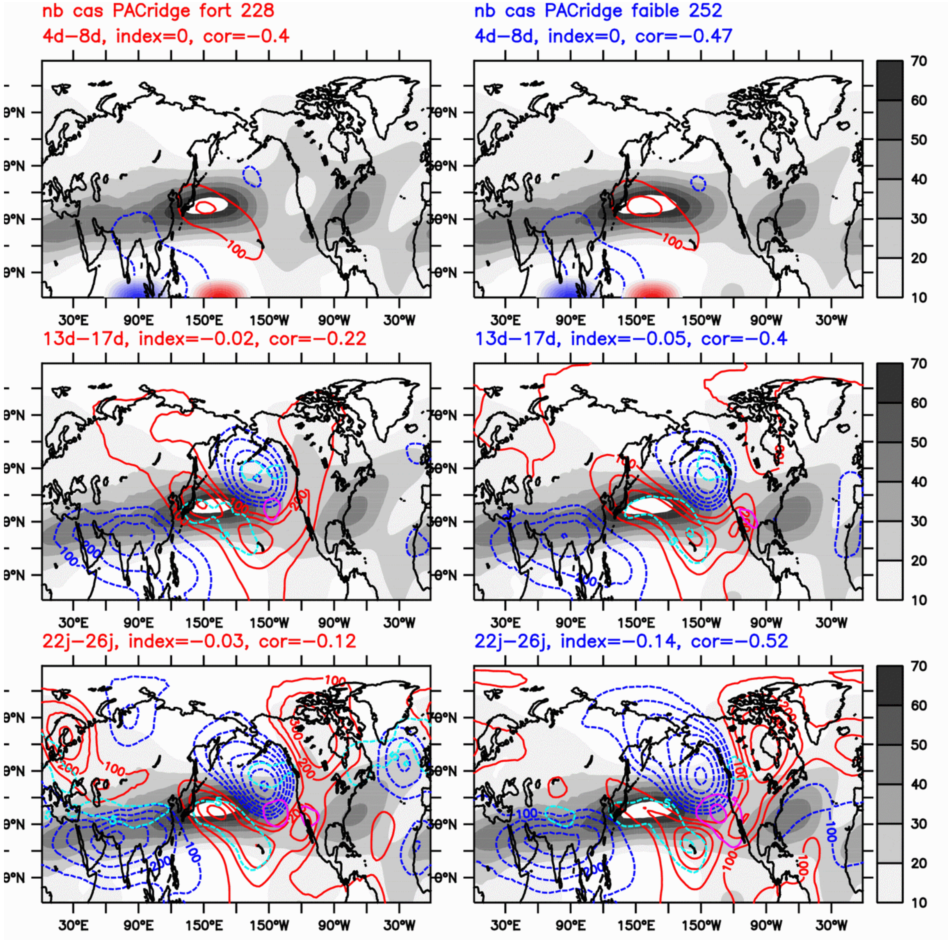
# Phase 6 impact as function of a pre-existing Pacific ridge/trough

Initial cond° with PAC ridge




Initial cond° with PAC trough

## Anomalous streamfunction with respect to control runs

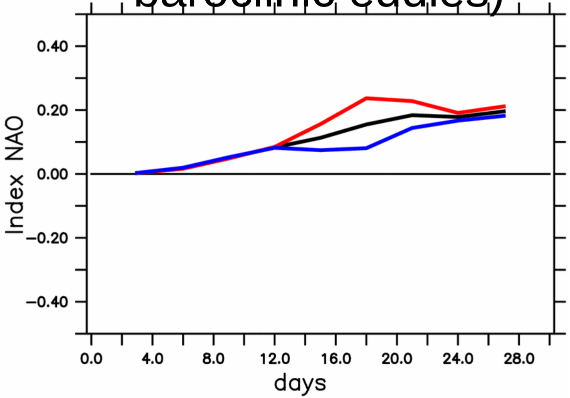


# Non stationary vs stationary background flow

Full model (inc baroclinic eddies)

Stationary wave model (wo baroclinic eddies)

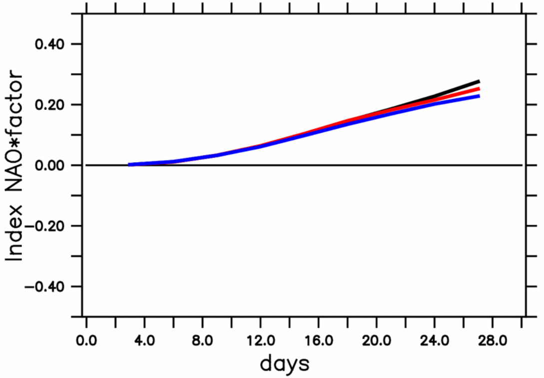
Phase 3



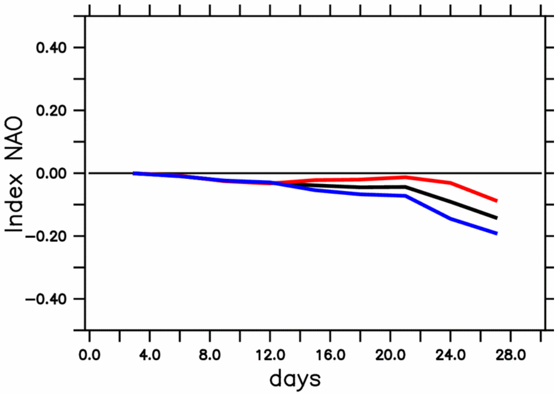

PAC ridge

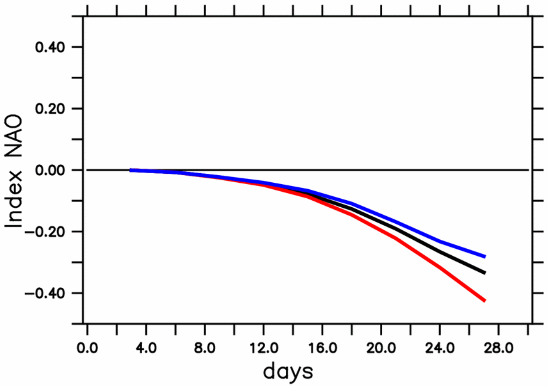
All cases

PAC trough

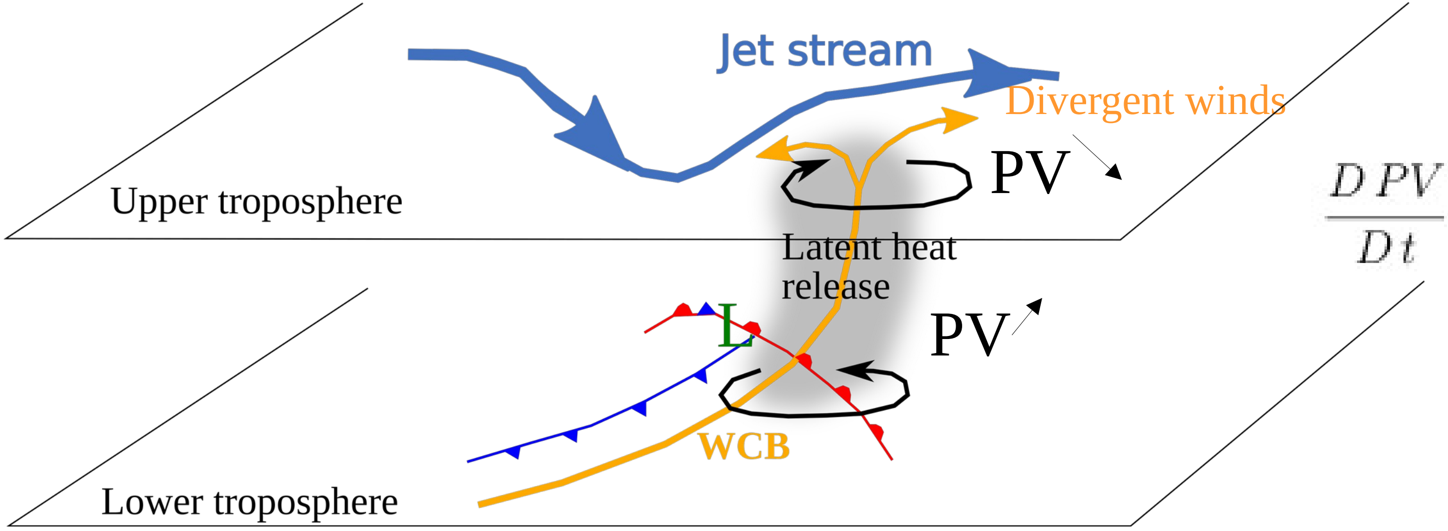



Phase 6



# The Potential Vorticity perspective of the NAWDEX community




$$\frac{D\,PV}{D\,t} \approx \frac{1}{\rho}\zeta_k \cdot \frac{\partial \dot{\theta}}{\partial z}$$

→ The diabatic PV modification at upper levels depends on the shape and intensity of the diabatic heating rate along WCBs

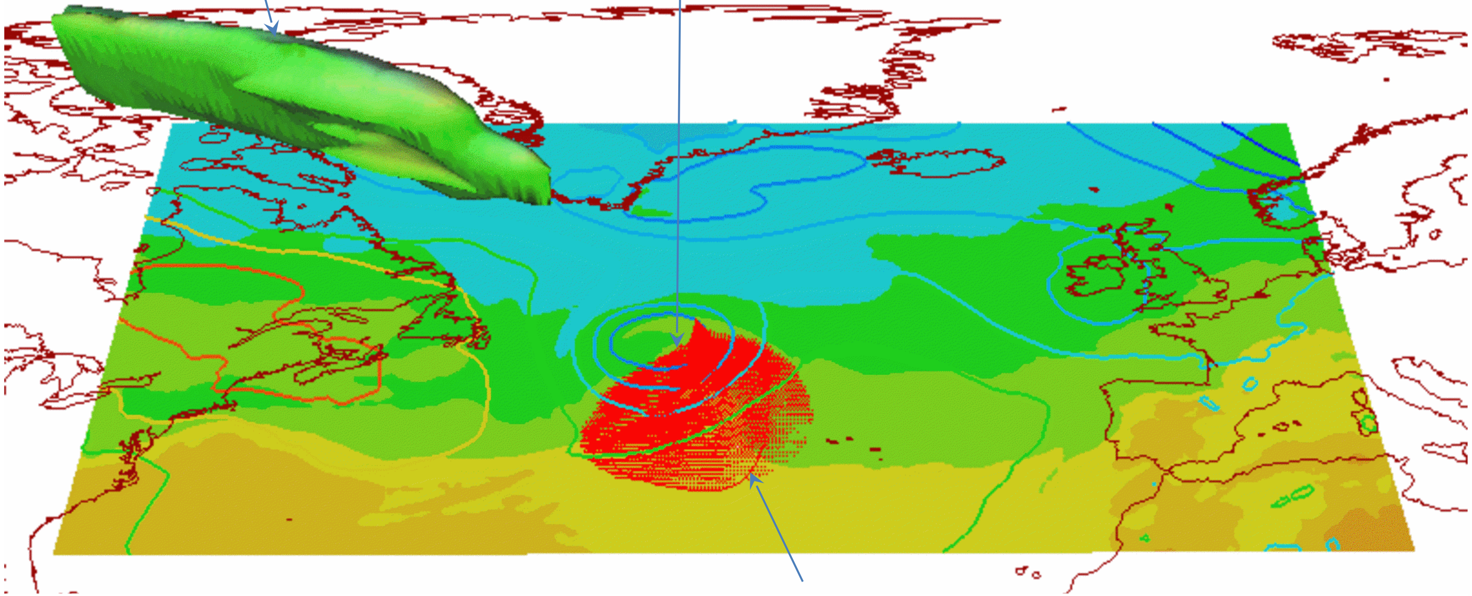
→ Potential source of forecast uncertainties

# Lien entre tempêtes et jet stream

Jet stream (Vent > 180 km/h)

Dépression

a) 1 October 2016, 00 UTC

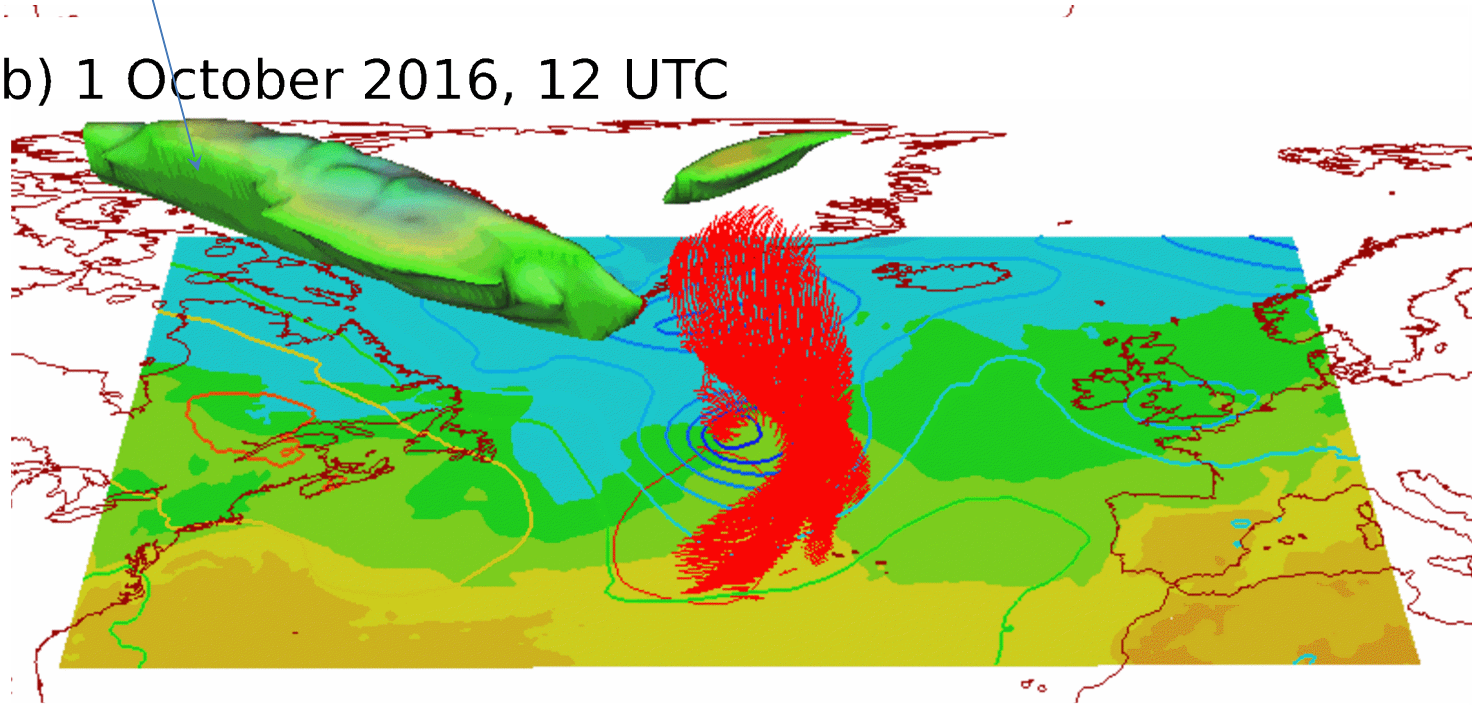


Initialisation trajectoires de masses d’air

# Lien entre tempêtes et jet stream

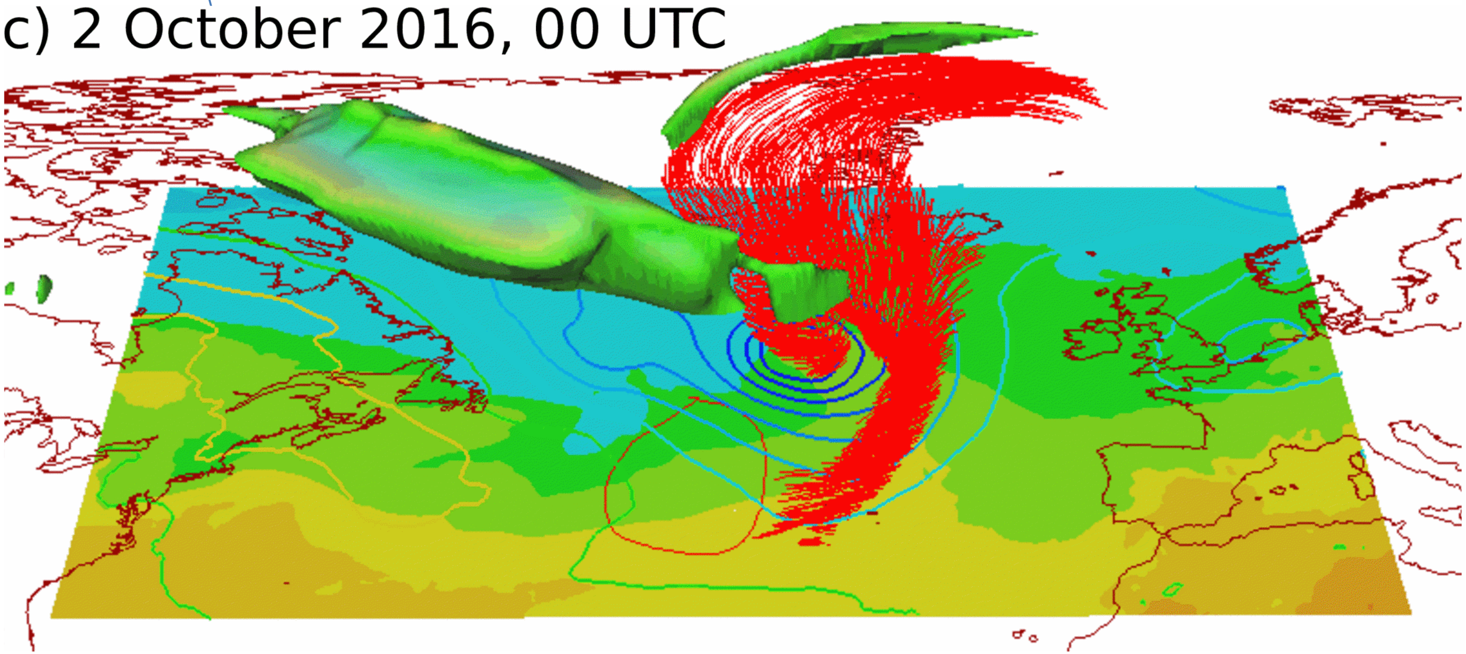
Jet stream (Vent > 180 km/h)

b) 1 October 2016, 12 UTC

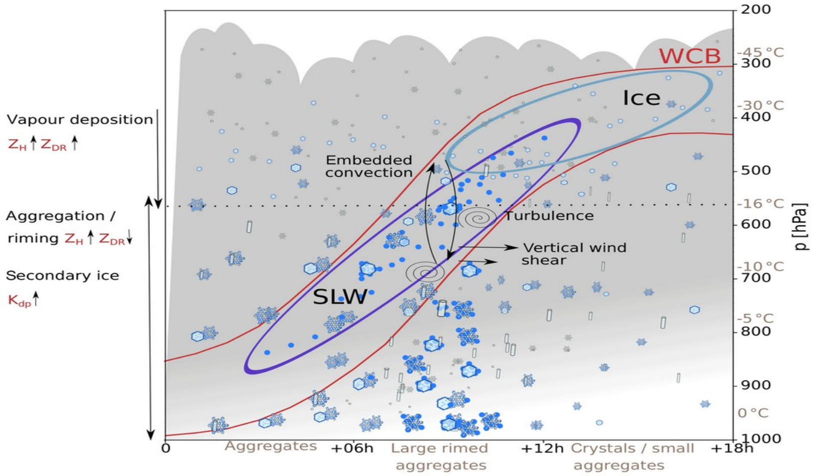


# Lien entre tempêtes et jet stream

Jet stream (Vent > 180 km/h)



# Cloud microphysics and warm conveyor belts




Gehring et al. (2020)

→ Latent heat release : ~ 20K over 48h (Madonna et al. 2014)

→ Multiple cloud microphysics processes occur within WCBs :

10 K due to condensation of vapour, depositional growth of snow (Joos and Wernli, 2012)

Riming, aggregation can be important (Gehring et al. 2020)

→ Sensitivity of WCBs and jet stream to different representations of clouds microphysics (Joos and Forbes, 2016)

# Addressed questions

**1- Which microphysical processes along WCBs have more impact on the jet stream ?**

**2- Which microphysical processes lead to the largest forecast uncertainties ?**

# Methodology

## Model

Meso-NH
mesoscale non-hydrostatic model

- → ΔXΔY → **2.5 km*2.5 km** (explicit convection)
- → 2-3 days forecasts of **NAWDEX IOPs** (mainly IOP6, and also IOP9) Output : every 15min
- → CI and forcing : Global operational model ARPEGE
- → Two cloud microphysics schemes ICE3 (Pinty and Jabouille, 1998) and LIMA (Vié et al. 2016)

## Tools

→ Lagrangian trajectories and PV framework
→ Double comparison in the model and observations space : radar simulator along flight track (Borderies et al. 2018) + cloud properties retrieval algorithm (Delanoe and Hogan, 2010 ; Cazenave, 2019)

# Comparison between 2 different microphysical schemes

Meso-NH
mesoscale non-hydrostatic model

## ICE3 (Actually used in French NWP model)

- - Droplet, rain, graupel, snow and ice **mass mixing ratio pronostic** (one-moment scheme)

- Cold phase (and mixed) :

- **-Deposition of all vapor in excess on ice and droplets** (adjustment to saturation)
- -Vapor deposition on snow and graupel only in mixed phase

**Subgrid condensation scheme**

- (allow to consider condensate in a mesh with RH < 100%)

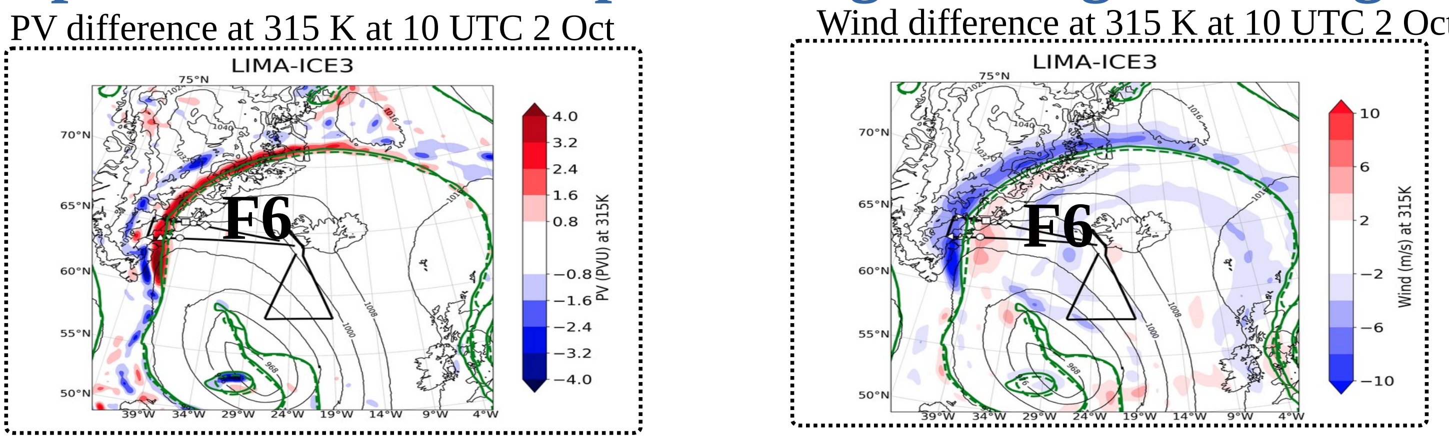
$\neq$

## LIMA (In future ?)

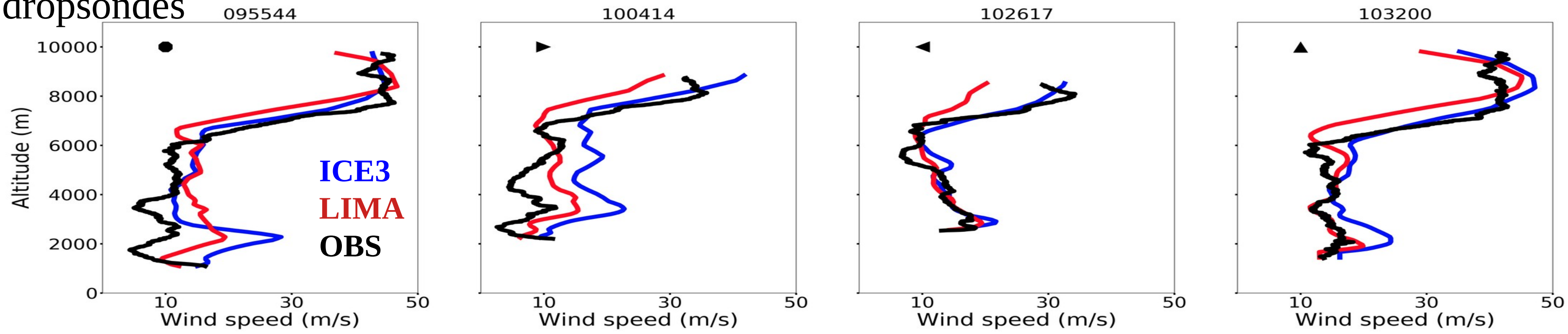
- - Droplets, rain, graupel, snow and ice **mass mixing ratio pronostics** and droplet, rain, ice **number concentrations pronostics** (quasi two-moments scheme)

- - Cold phase (and mixed) :
- - **Explicit vapor deposition on ice, snow and graupel**

# Which run perfoms better in representing the ridge building ?



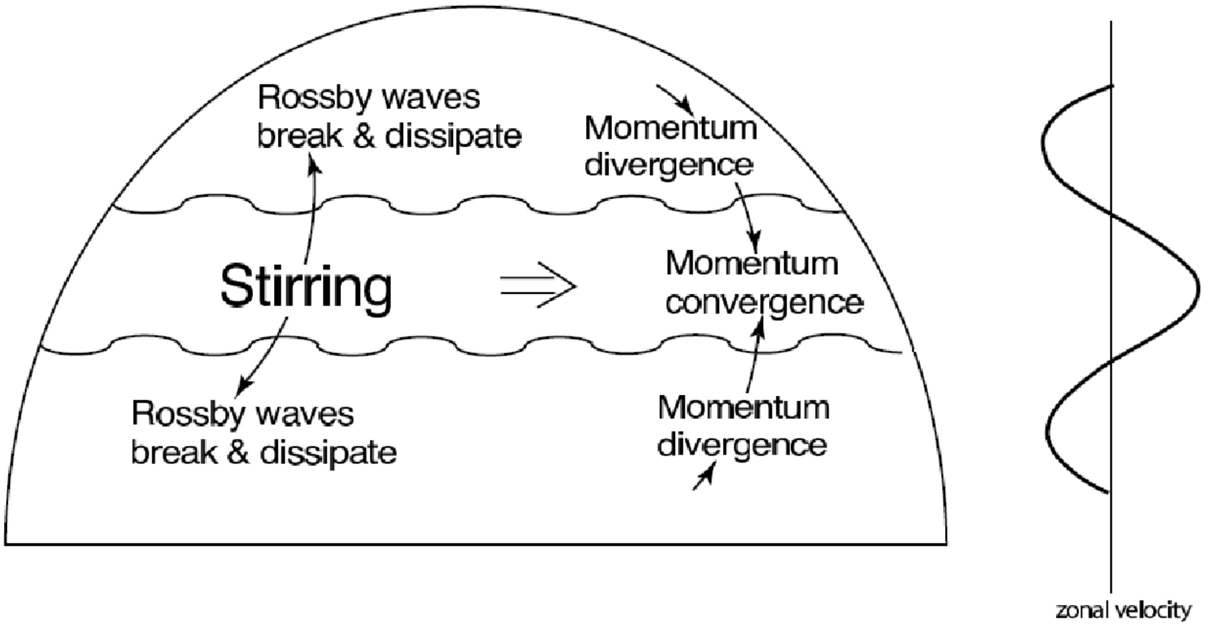

dropsondes




→ ICE3 better represents the leading edge of the ridge building

→ *Discrepancies between ICE3 and LIMA is supposed to rely on vapor deposition on ice*

# Eddy-driven jets processes




- *Schematic of Rossby wave propagation from a stirring region, momentum transport and impact on the zonal mean flow.* *D’après Vallis (2006)*

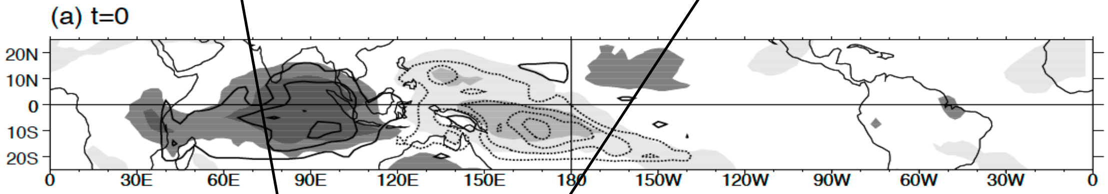
# The Madden Julian Oscillation (MJO)

*(Madden & Julian 1971, 1972)*

**Dominant mode of intraseasonal variability in the tropics**

Enhanced convection

Reduced convection




*Outward Longwave Radiation (OLR) – from Matthew et al. (2004)*

## Main properties

- Coupled enhanced/suppressed convection dipole propagating eastward ($v_{prop}$~5 m/s)
- Typical period ~ 40-50 days
- Appear in Indian Ocean – weakens in eastern Pacific

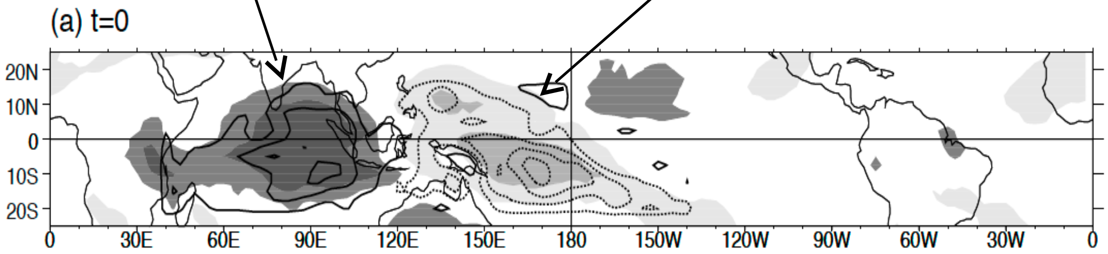
# *The Madden Julian Oscillation (MJO)*

*(Madden & Julian 1971, 1972)*

**Dominant mode of intraseasonal variability in the tropics**

Enhanced convection

Reduced convection




*Outward Longwave Radiation (OLR) – from Matthew et al. (2004)*

## Main properties

•Coupled enhanced/suppressed convection dipole