# On the relationship between sub-seasonal and interannual teleconnections from Indo-Pacific heating

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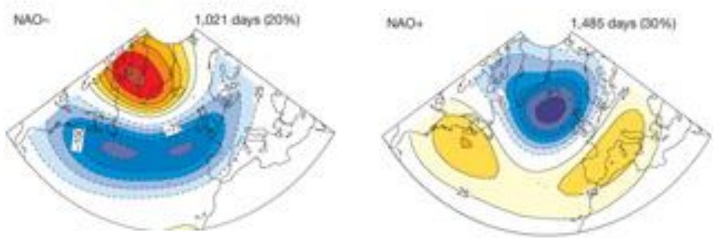
# Main question

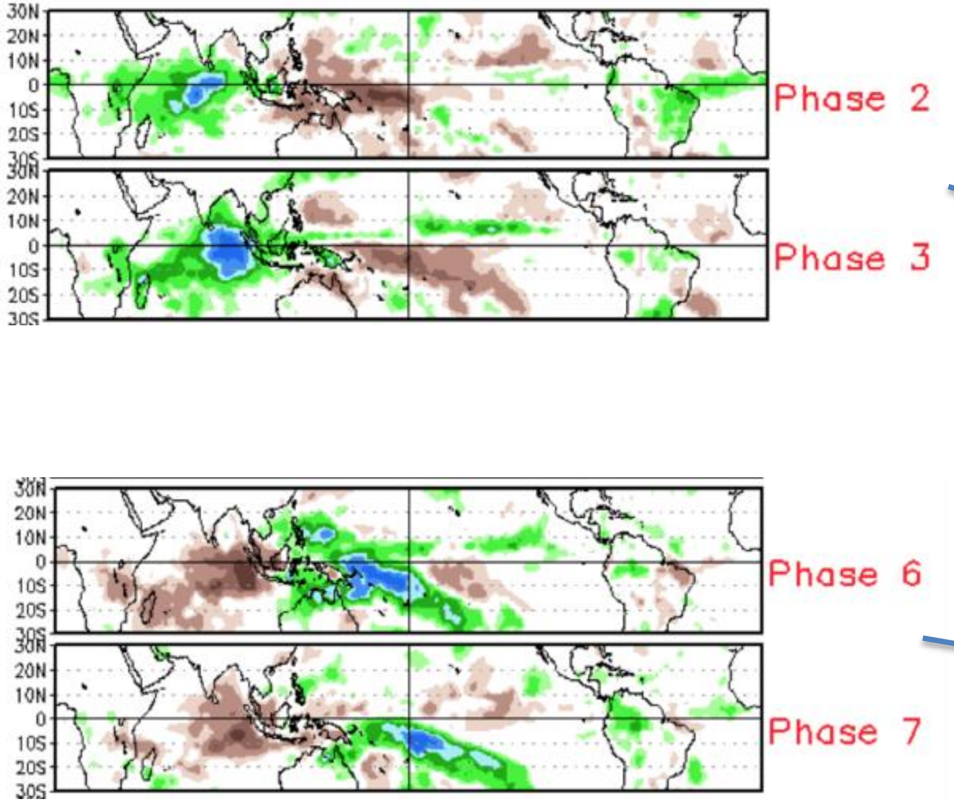
- On sub-seasonal time scales, teleconnections between the Madden-Julian Oscillation and the North Atlantic circulation anomalies appear to be stronger when heating anomalies are located in the eastern Indian Ocean (MJO phase 3 -> +NAO)
- On the seasonal to interannual scale, a positive North Atlantic Oscillation is connected with positive heating anomalies in the western-to-central part of the Indian Ocean

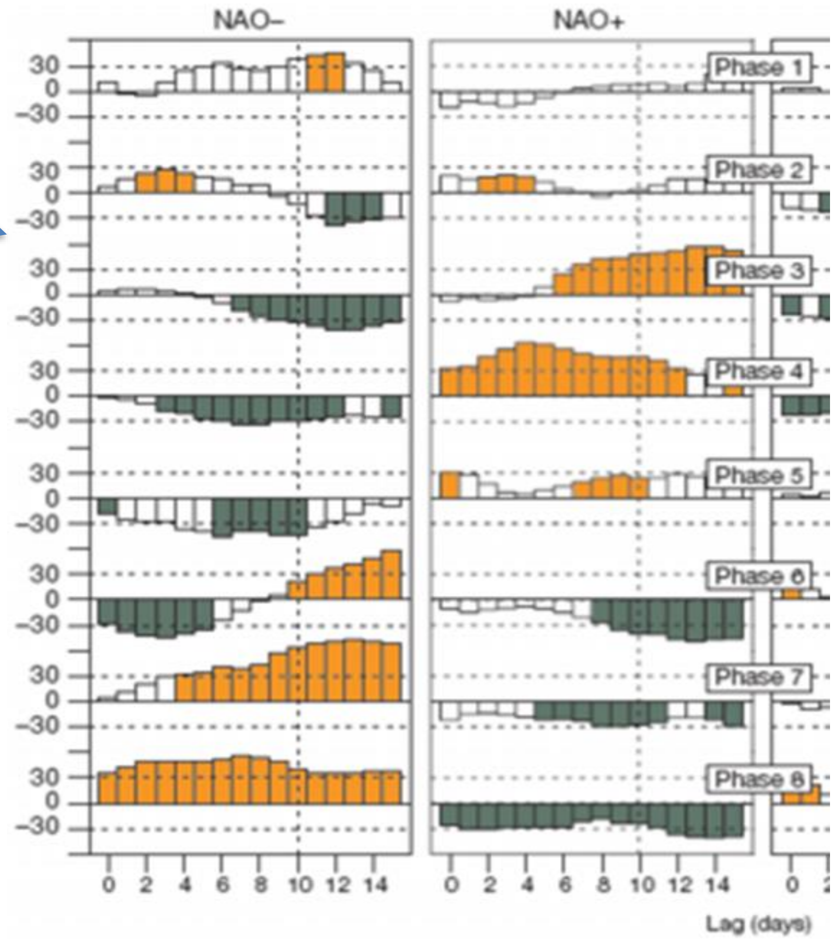
Possible reasons for this discrepancy:

  - MJO indices (Wheeler-Hendon) are mostly determined by zonal wind anomalies
  - MJO teleconnections reflect the superposition of signals originated from a propagating heat source
  - Interannual teleconnections from Indian Ocean / Maritime Continents are strongly affected by ENSO
  - Different methodologies used in diagnostics: regression maps/composites/regime frequencies, time filtering, different definition of “seasons”, number and intensity of ENSO events in the data sample, different variables used as predictors (OLR, rainfall, combined wind/OLR) and/or predictands (sea-level pressure, geop. height)

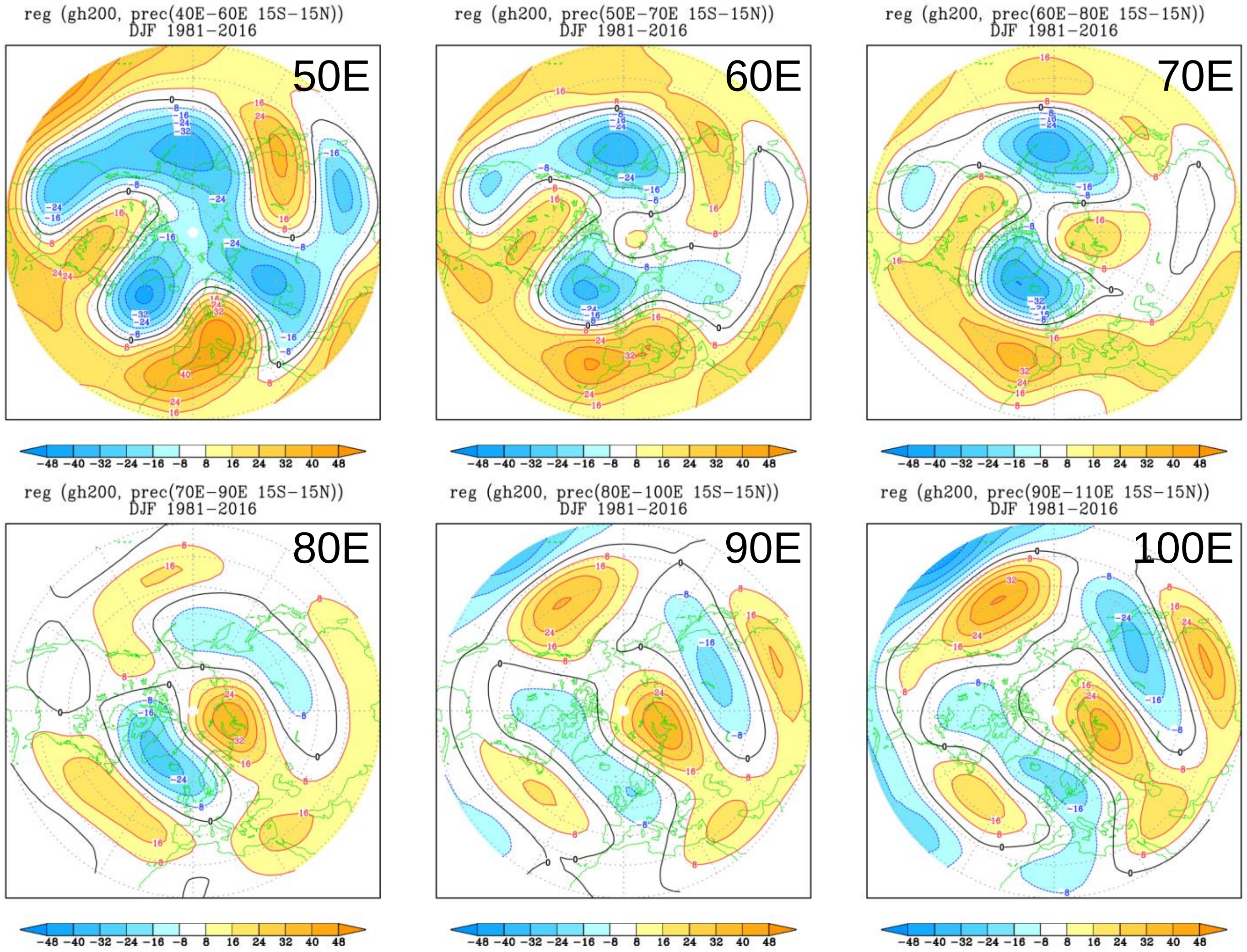
# N. Atlantic regime frequencies are affected by MJO phase (Cassou, Nature 2008, and many others!)



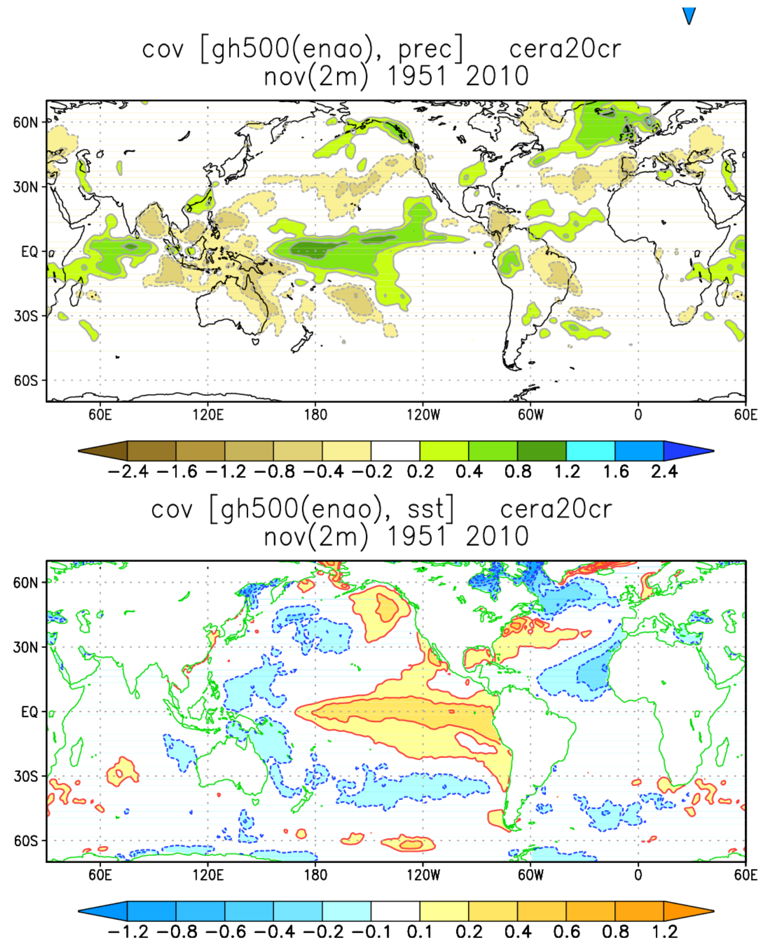



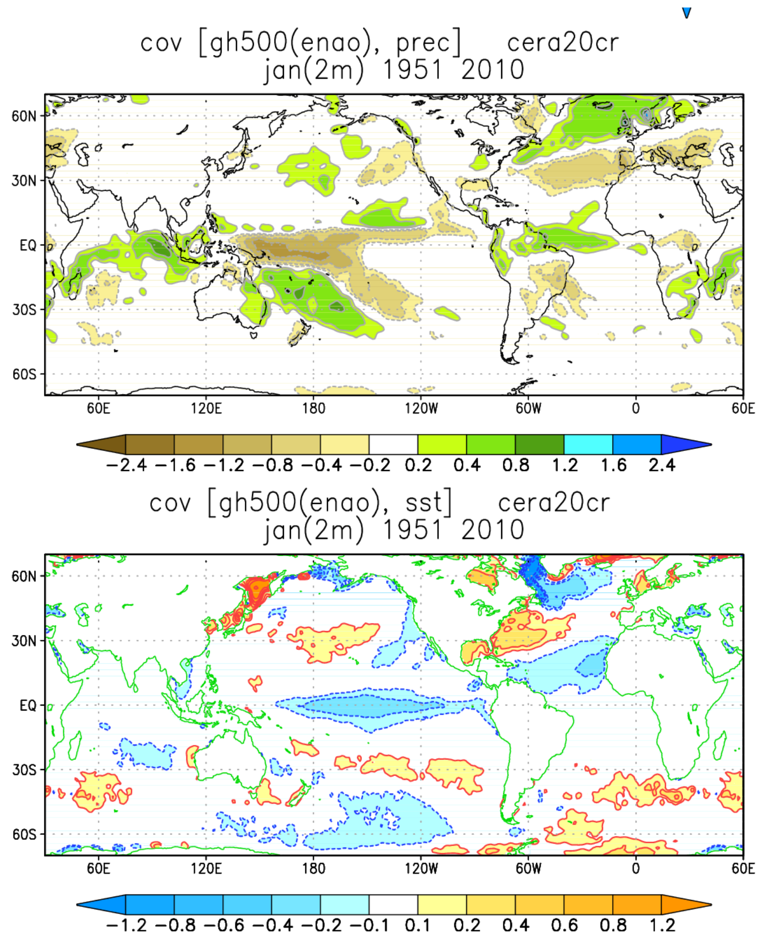
# Regression of Z.200 DJF-means on rainfall in eq. Indian Ocean (15N-15S) data: ERA-5/GPCPv2.3, 1981-2016, 36 years



# The relationship between NAO and Pacific rainfall/SST is different between early and late winter




Nov-Dec




Jan-Feb

# Numerical simulation of the response to I.O. heating anomalies

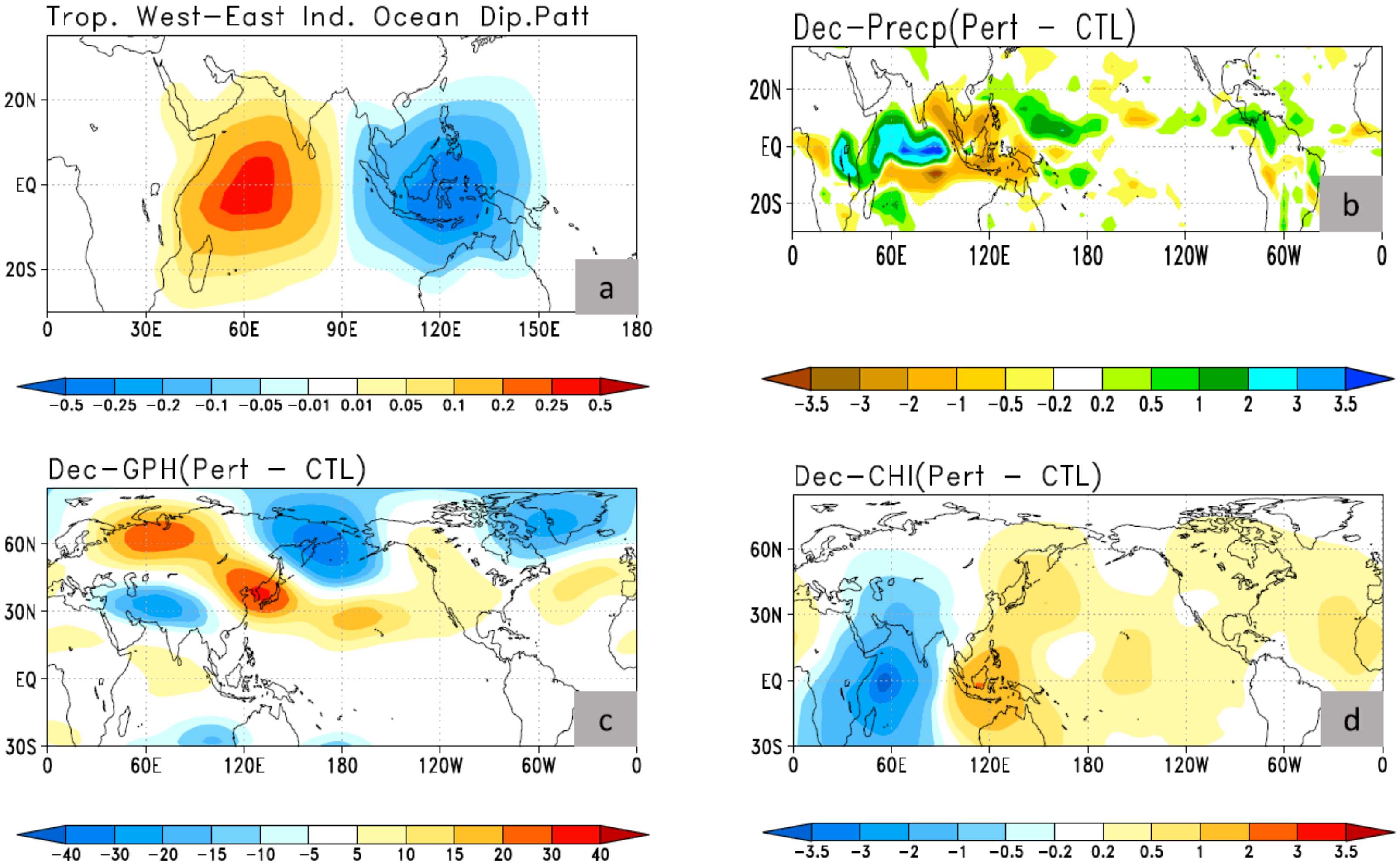



FIG. 11. (a) Tropical western (heating) and eastern (cooling) Indian Ocean (TWEIO) pattern for the idealized simulations (K $day^{-1}$). (b) Precipitation (Pert − CTL) response to the dipole (western warm/eastern cold) heating anomalies shown in (a) (mm $day^{-1}$) based on 139 ensemble members. (c) As in (b), but for 200-hPa geopotential height anomalies (m). (d) As in (c), but for 200-hPa velocity potential anomalies ($\times 10^6\ m^2\ s^{-1}$).

Abid et al.,
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# Teleconnections from tropical diabatic heating: an observational and modelling study (ECMWF-COLA collaboration)

**ERA-5 re-analysis data**: diabatic heating in 9 atm. layers computed by D . Straus as a difference between total and adiabatic temperature tendencies (from T, u, v, ω every 6hr)

**Sub-seasonal ensembles**:

- IFS TCo319L91 / NEMO ORCA025-Z75, 60 days, 1 control + 8 / 50 pert. members
- no initial perturbations
- Stochastic physics (SPPT) only active in 50E-120E, 20S-20N (tapered to zero in a 5-deg window all around)
- Diabatic heating computed in three layers (1000-850, 850-400, 400-50 hPa from 12-hr data)
- 36-year experiments for Nov-Dec and Jan-Feb: init. dates 1 Nov./1 Jan. 1981-2016 (9 members)
- Extended ensembles in years with MJO phase 2/3 at initial time (51 members):
  - 1 Nov I.C.: 1986, 1987, 1990, 2001, 2002, 2004, 2011, 2015
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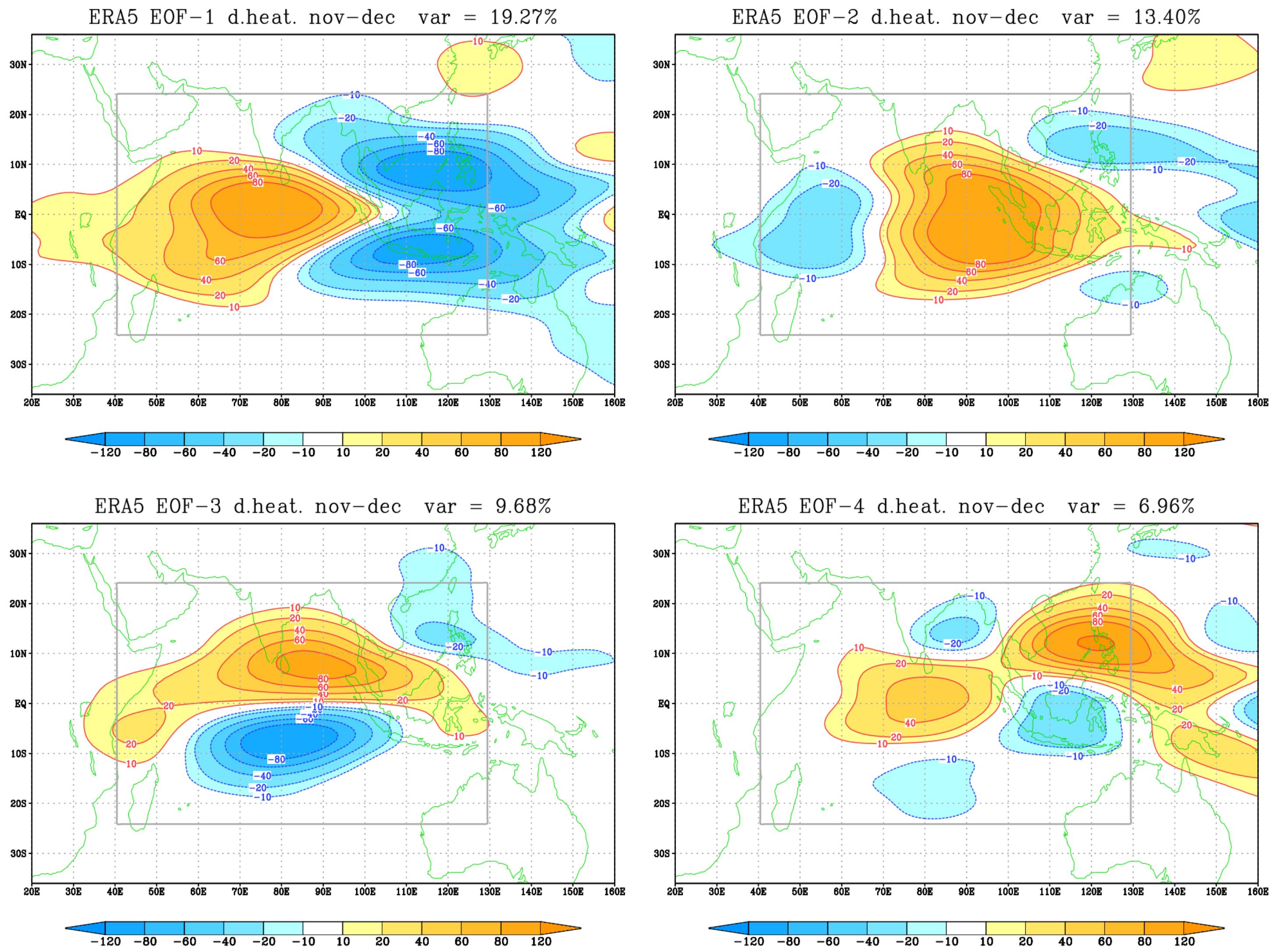
# EOFs of diabatic heating in the Indian Ocean (zonal wn. 0-8 filter): ERA-5, Nov-Dec 1981-2016, 36 years



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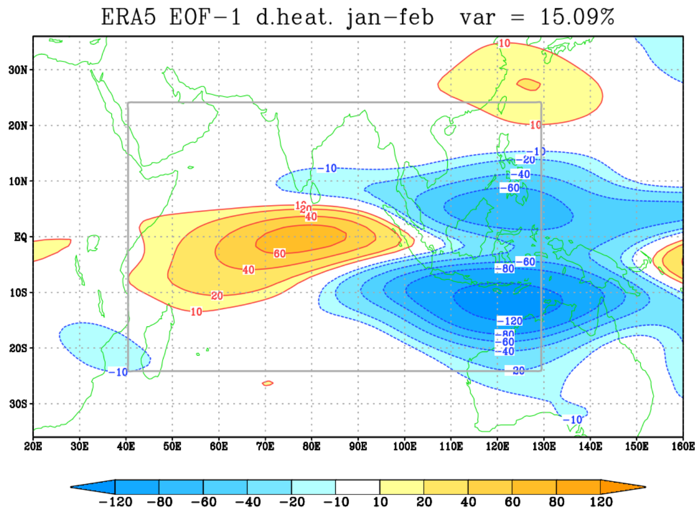
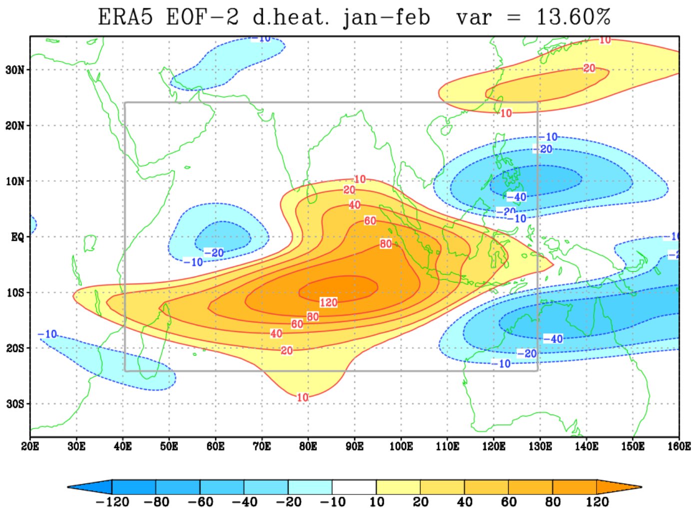
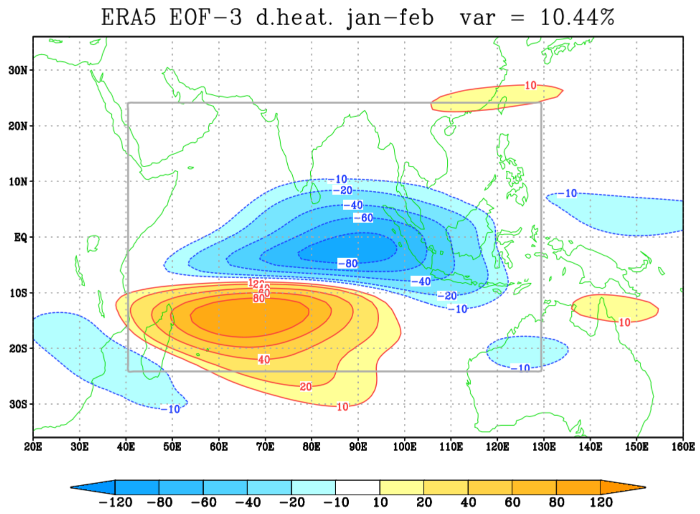
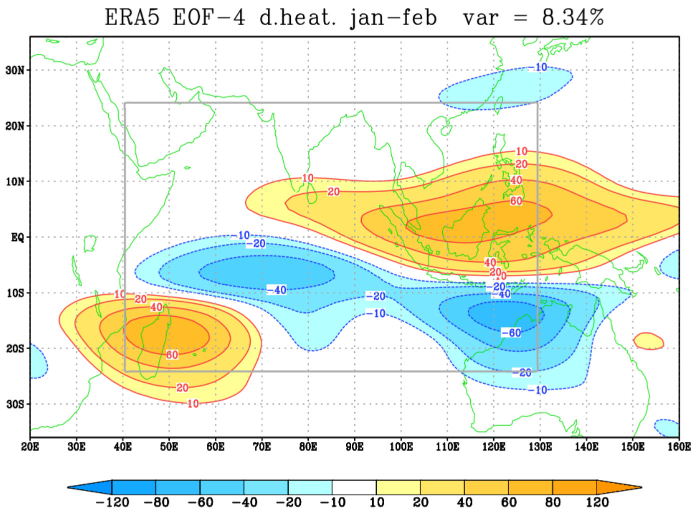
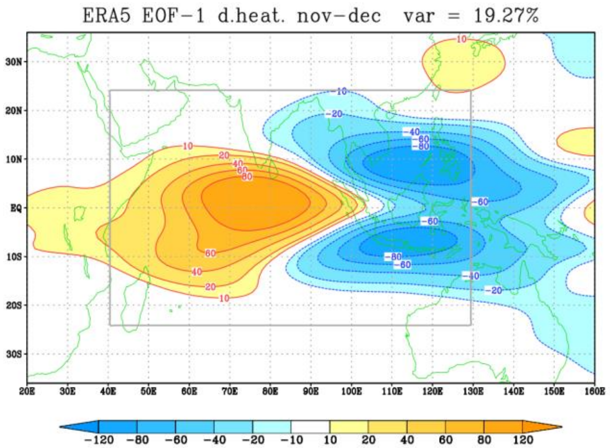


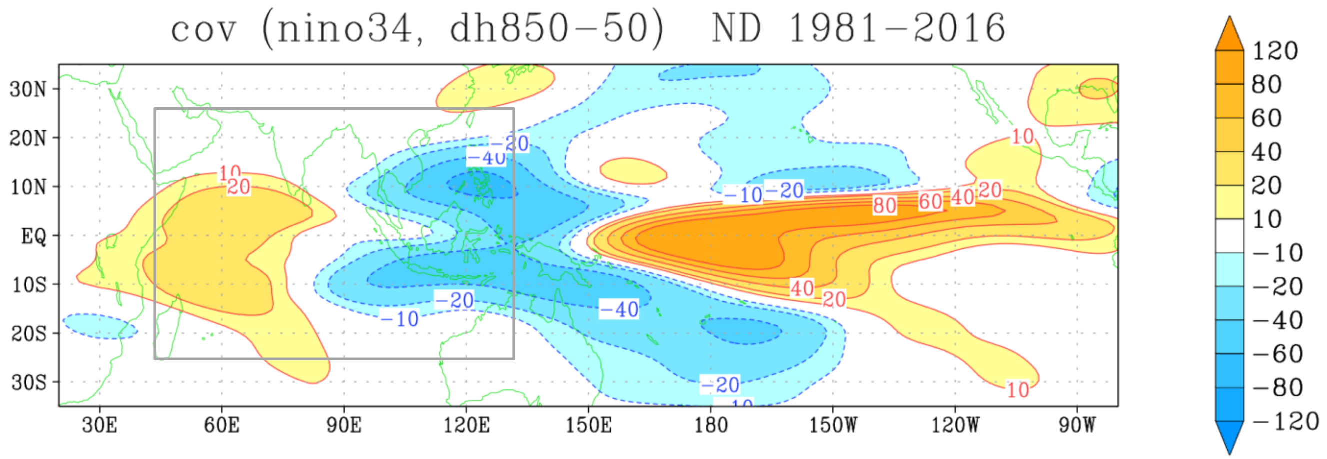



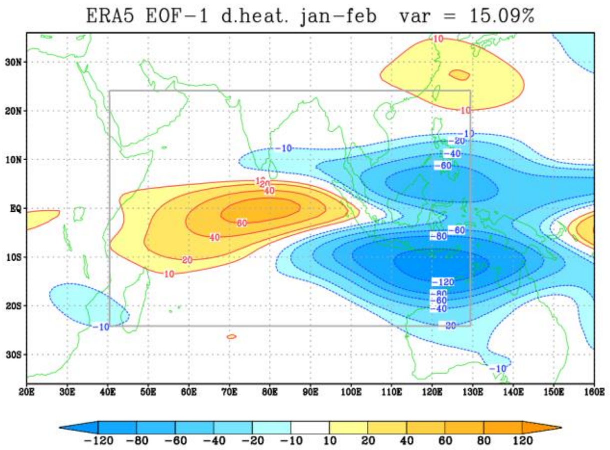



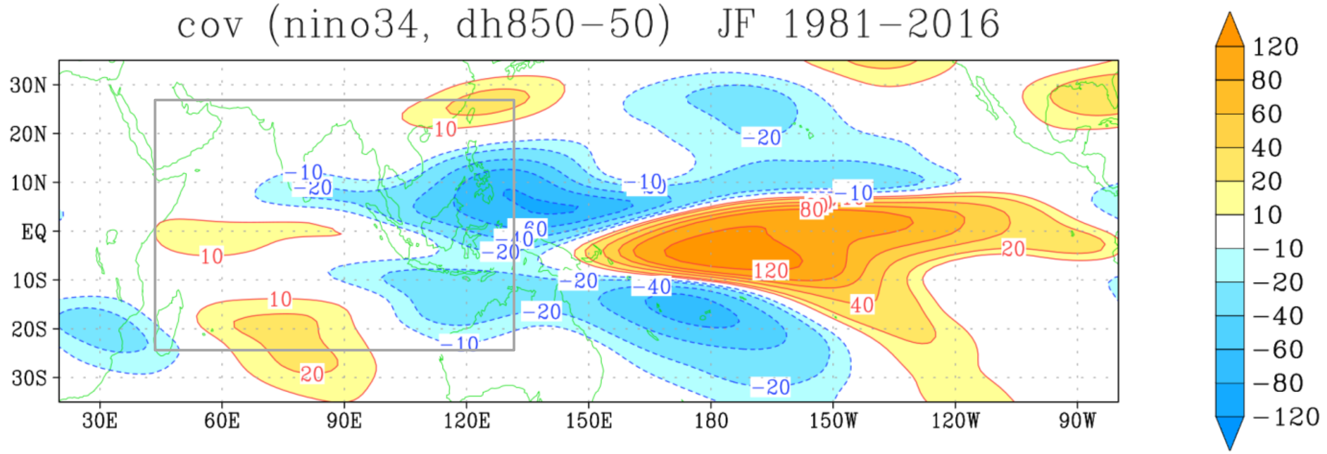



# Covariance of 850-50-hPa diab. heating with Nino3.4 SST



# Regression of anomalies on normalised PCs at different time scales

- PC ($t_s$, $t_{ia}$)  $t_s$ = 1, … 12 pentads from 1Nov/1Jan, $t_{ia}$ = 1981, …, 2016
- A ($\underline{x}$, $t_s$, $t_{ia}$)  anomaly over spatial domain $\underline{x}$
- Regression of A on PC:  $A_r(\underline{x}, t_s, t_{ia}) = \mathbf{R}(\underline{x}) \cdot PC(t_s, t_{ia})$

- Seasonal means and sub-seasonal deviations of PCs:
  - $PC_m(t_{ia})$ = ave { $PC(t_s, t_{ia})$, $t_s$=1-12 pen. }
  - $PC_s(t_s, t_{ia}) = PC(t_s, t_{ia}) - PC_m(t_{ia})$

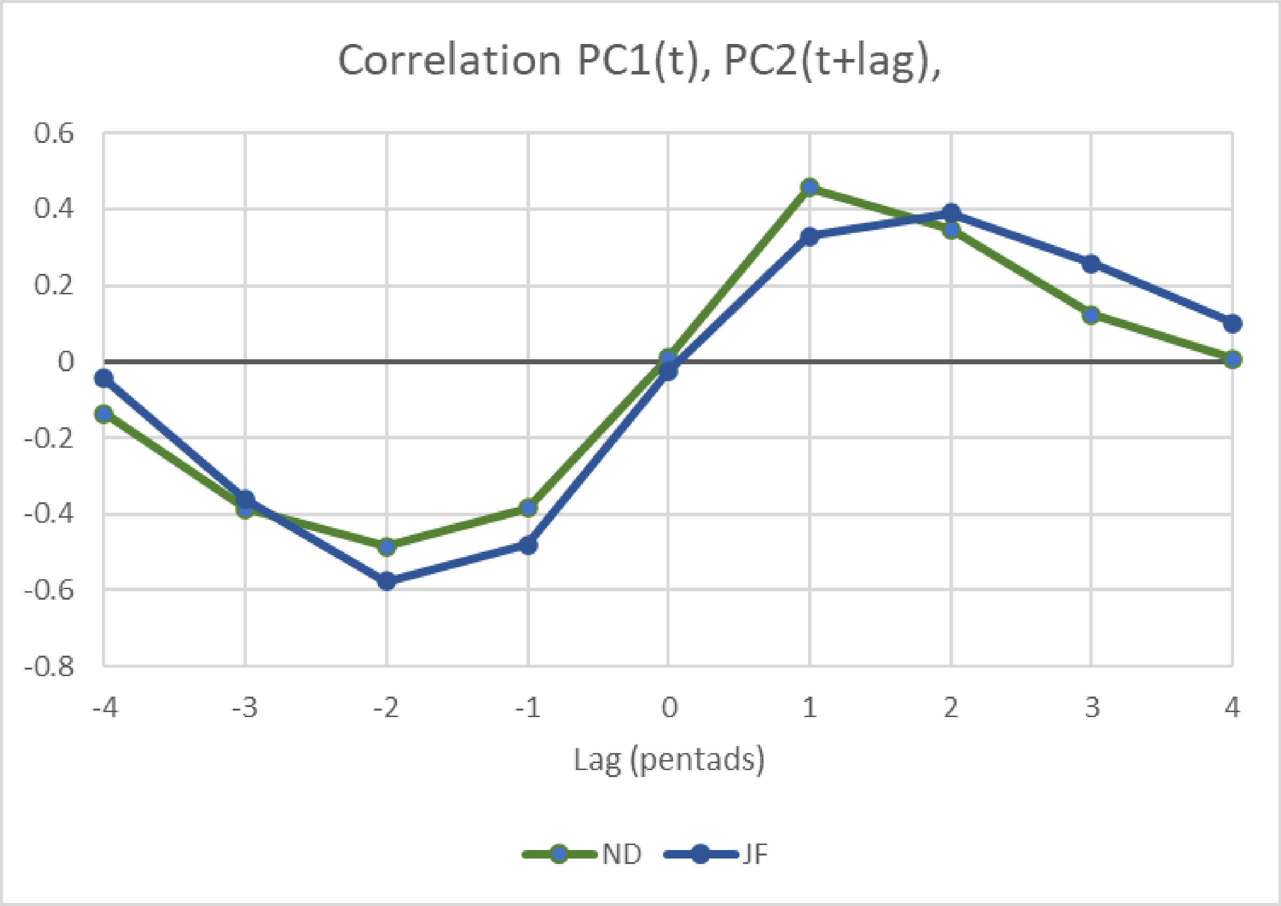
- Decomposition of regression into inter-annual and sub-seasonal components
  - $A_r(\underline{x}, t_s, t_{ia}) = \mathbf{R_{ia}}(\underline{x}) \cdot PC^*_m(t_{ia}) + \mathbf{R_s}(\underline{x}) \cdot PC^*_s(t_s, t_{ia})$
  - $PC^*_m(t_{ia}) = PC_m(t_{ia}) / \sigma(PC_m)$ , $PC^*_s(t_s, t_{ia}) = PC_s(t_s, t_{ia}) / \sigma(PC_s)$

# Inter-annual and sub-seasonal variance of diabatic heating PCs

| | RMS amplitude of EOF ($W/m^2$) | Interannual variance(%) | Sub-seasonal variance (%) | Correl (Nino34, seas.mean PC) |
|---|---|---|---|---|
| **ND PC1** | 44.8 | 39.6 | 60.4 | 0.713 |
| **ND PC2** | 37.3 | 20.8 | 79.2 | -0.375 |
| **JF PC1** | 39.6 | 28.5 | 71.5 | 0.687 |
| **JF PC2** | 37.6 | 14.8 | 85.2 | 0.153 |

- Proportion of interannual variance is twice as large in PC1 than in PC2
- Correlation with Nino3.4 SST explains ~ half of the interannual variance of PC1

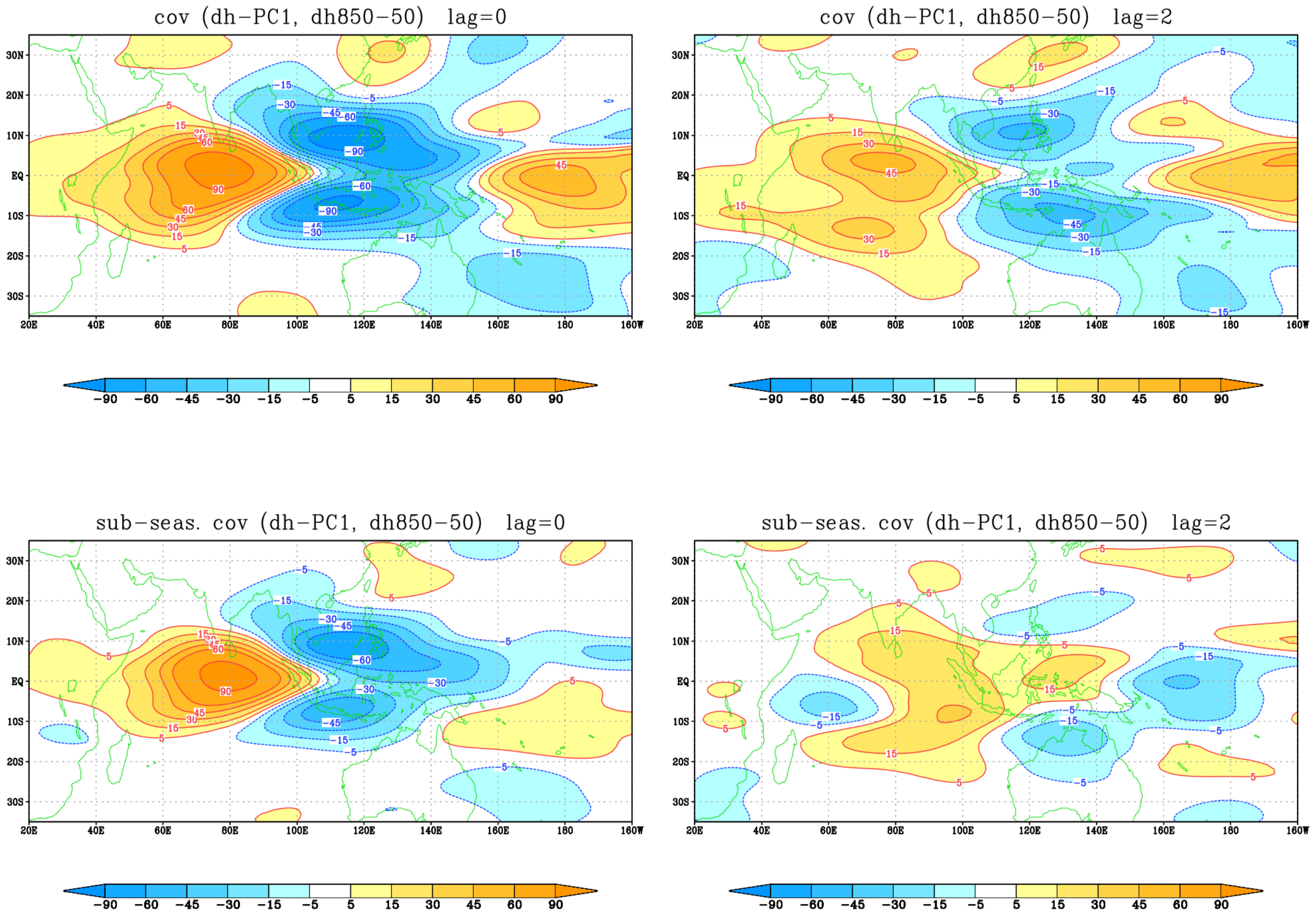
# Lag correlation of diabatic heating PCs (sub-seasonal)



# Regression of diabatic heating anomalies on d.h. PC1
# ERA-5, Nov-Dec 1981-2016

Total anomalies

Sub-seas. anomalies



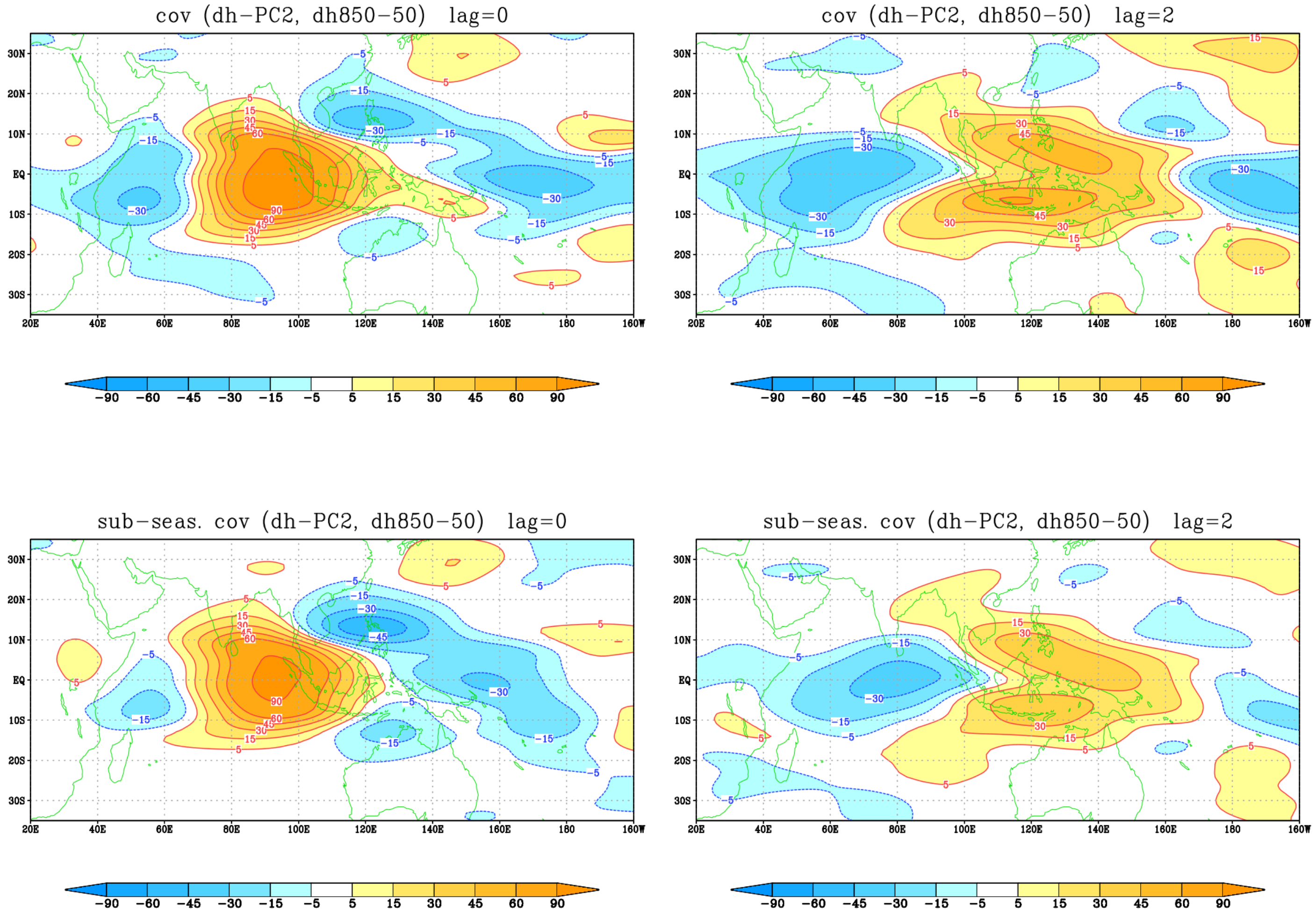

lag = 0

lag = 10 days

# Regression of diabatic heating anomalies on d.h. PC2
# ERA-5, Nov-Dec 1981-2016

Total anomalies

Sub-seas. anomalies




lag = 0

lag = 10 days

# Teleconnections from tropical diabatic heating: an observational and modelling study (ECMWF-COLA collaboration)

**ERA-5 re-analysis data**: diabatic heating in 9 atm. layers computed by D . Straus as a difference between total and adiabatic temperature tendencies (from T, u, v, ω every 6hr)

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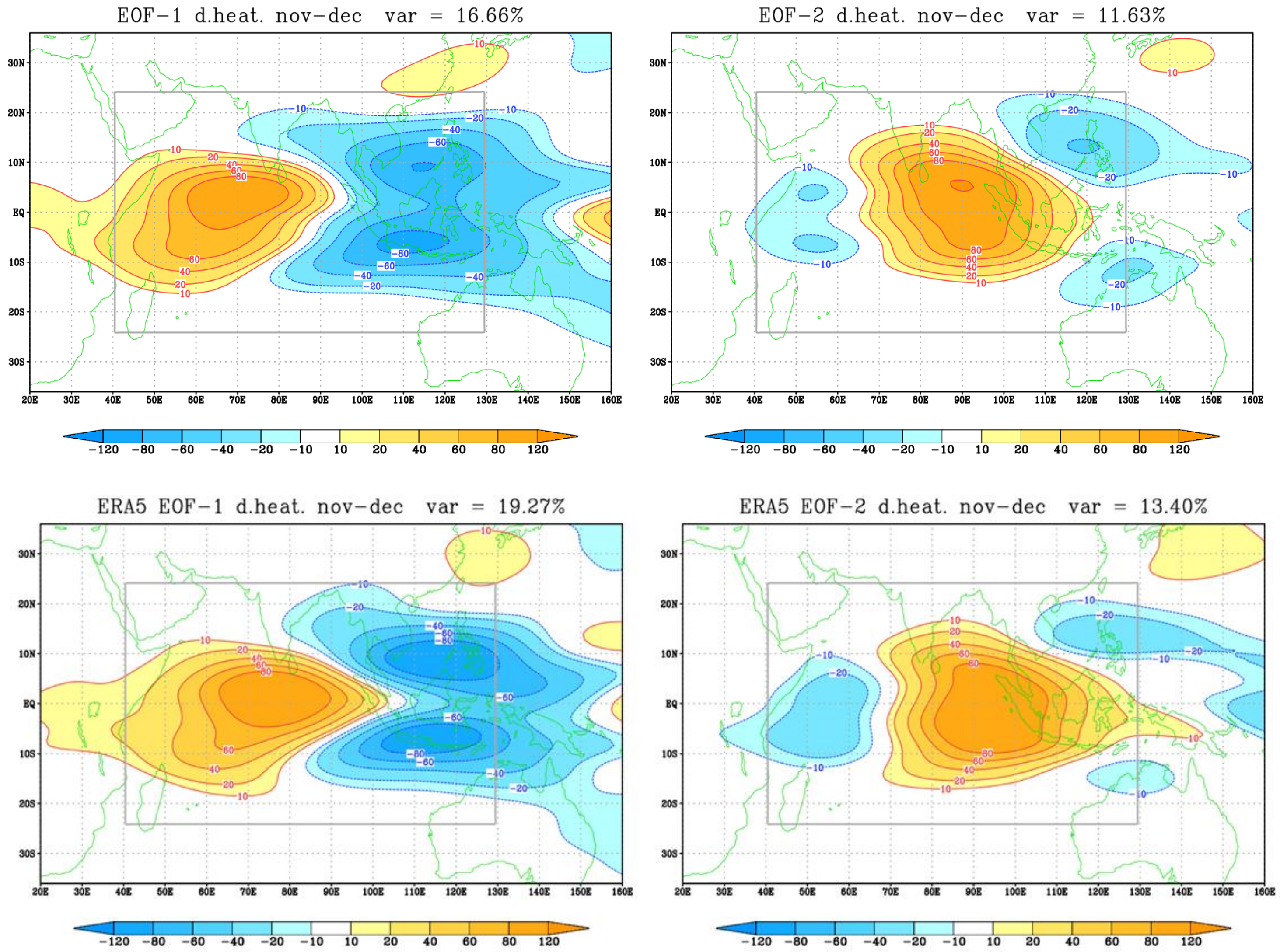
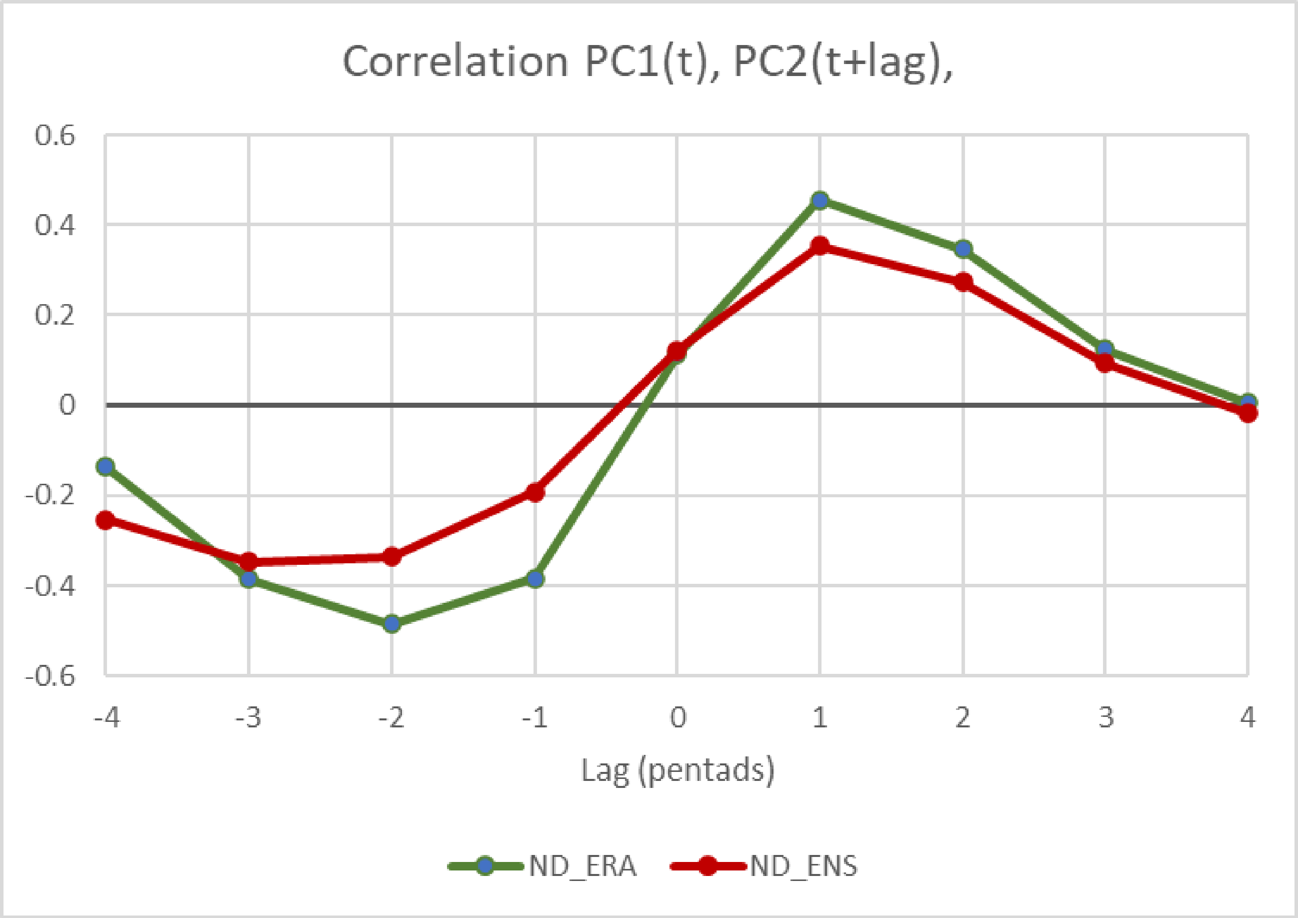
# EOFs of diabatic heating in the Indian Ocean (zonal wn. 0-8 filter): 1 Nov. ensembles, 1981-2016, 36 years



# Inter-annual and sub-seasonal variance of diabatic heating PCs (ND)

| | RMS amplitude of EOF ($W/m^2$) | Interannual variance(%) | Sub-seasonal variance (%) | Correl (Nino34, seas.mean PC) |
|---|---|---|---|---|
| **ND PC1** | 44.8 | 50.2 | 49.8 | 0.778 |
| **ND PC2** | 37.3 | 18.3 | 81.7 | -0.238 |
| **ND PC1 (ERA)** | 42.3 | 39.6 | 60.4 | 0.713 |
| **ND PC2 (ERA)** | 35.3 | 20.8 | 79.2 | -0.375 |

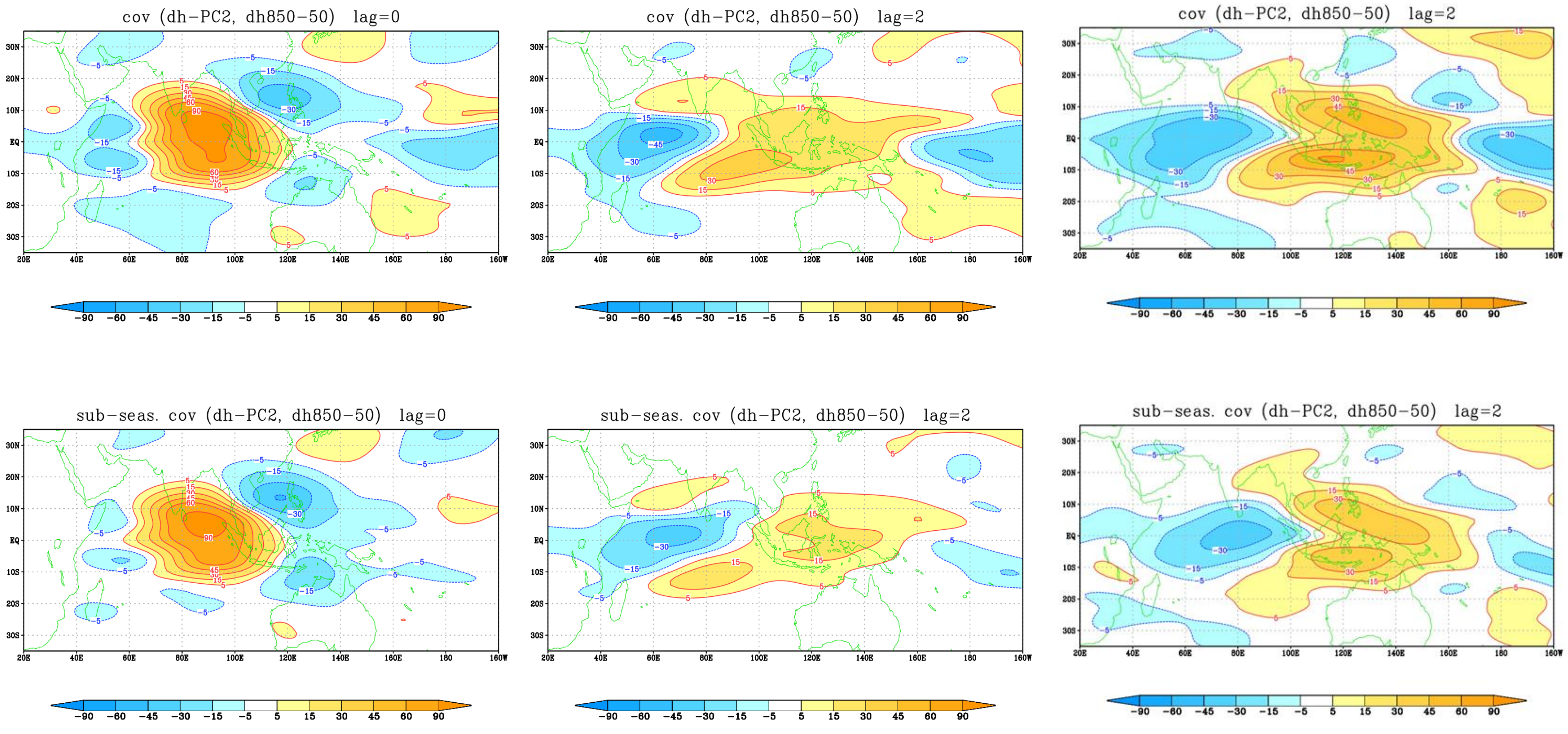
# Lag correlation of diabatic heating PCs, Nov-Dec (sub-seasonal)



# Regression of diabatic heating anomalies on d.h. PC2
## 1.Nov_ensembles, Nov-Dec 1981-2016

Total anomalies

Sub-seas. anomalies

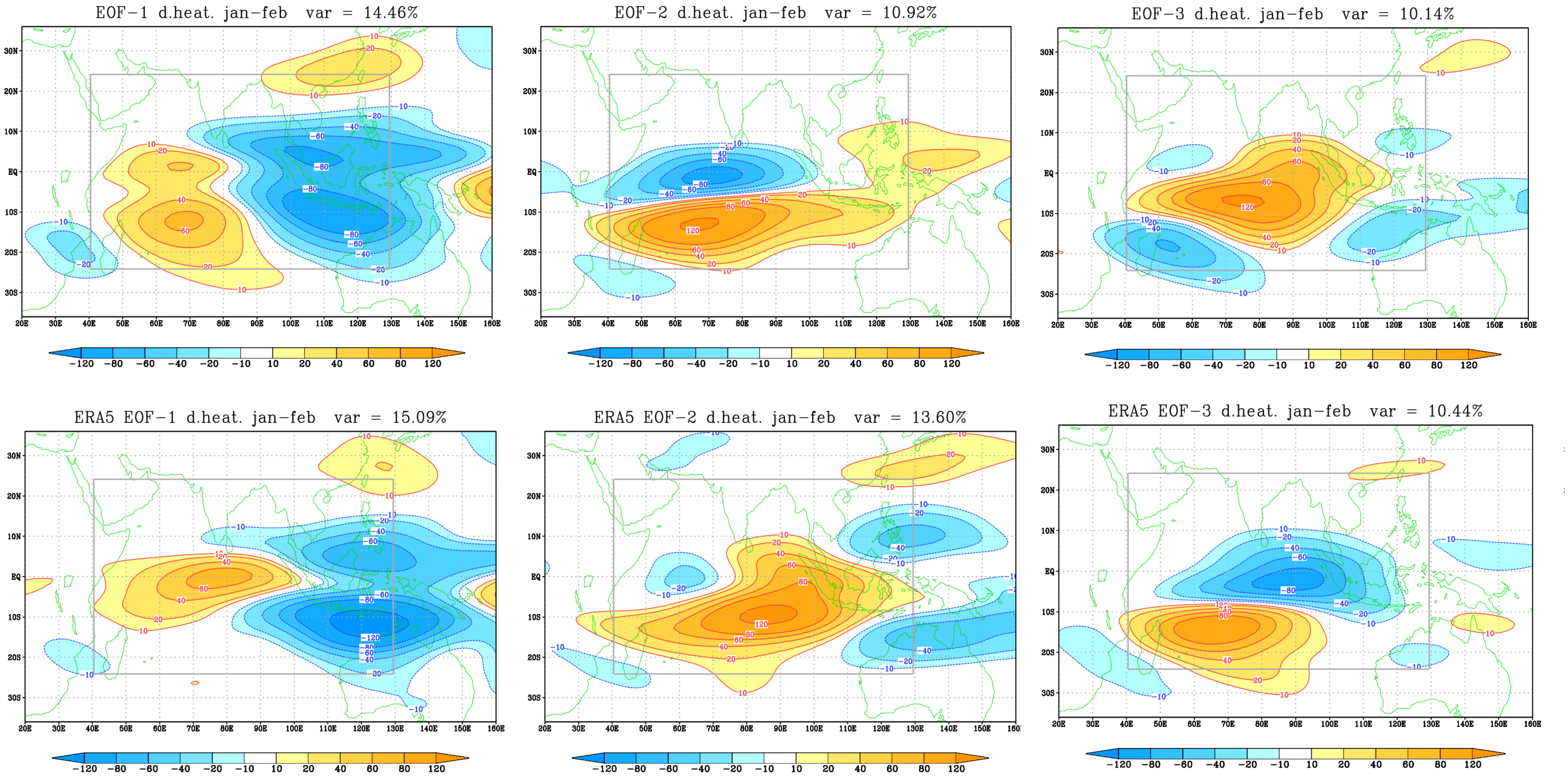



lag = 0

lag = 10 days

ERA

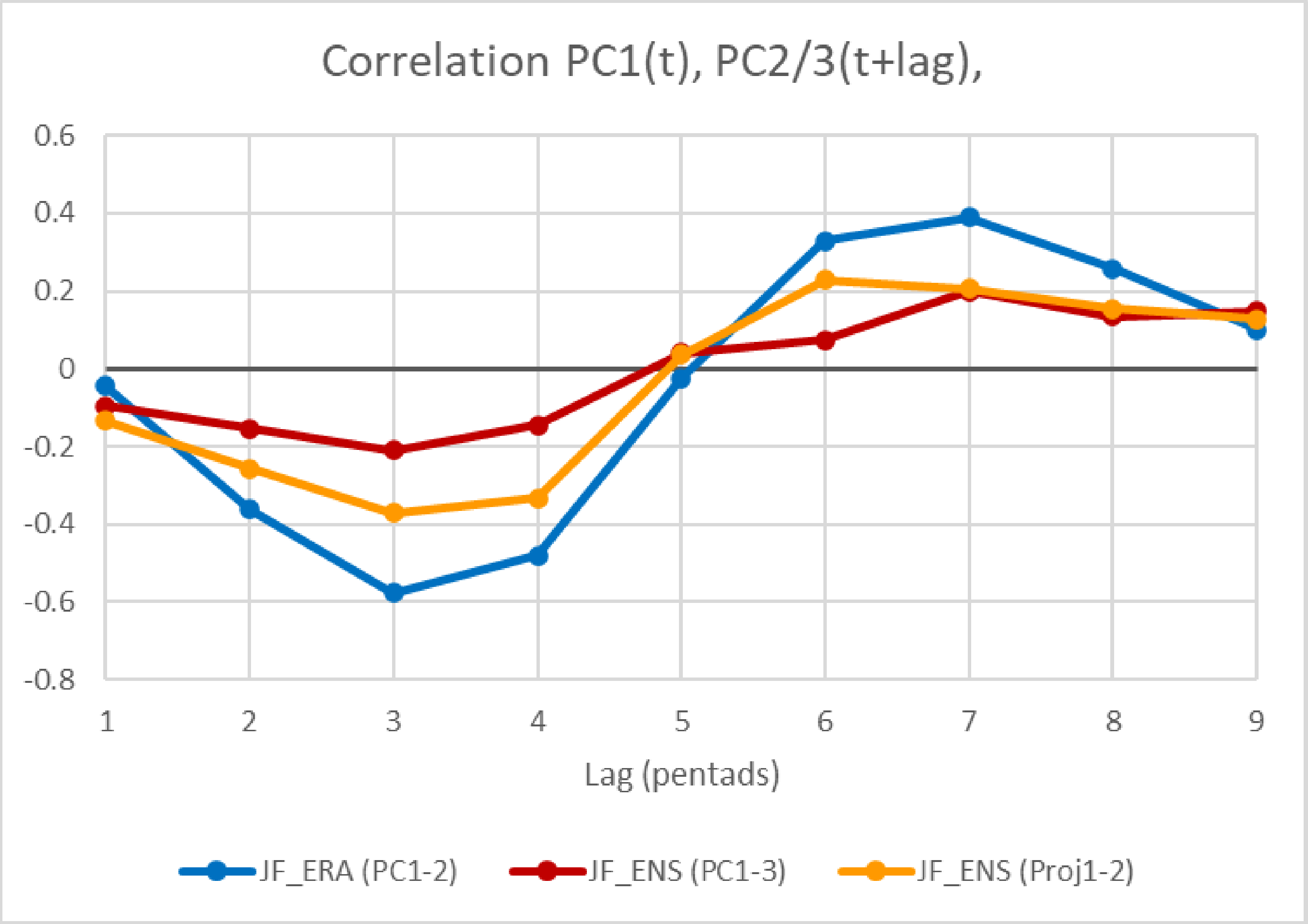
# EOFs of diabatic heating in the Indian Ocean (zonal wn. 0-8 filter): 1 Jan. ensembles, 1981-2016, 36 years



# Inter-annual and sub-seasonal variance of diabatic heating PCs (JF)

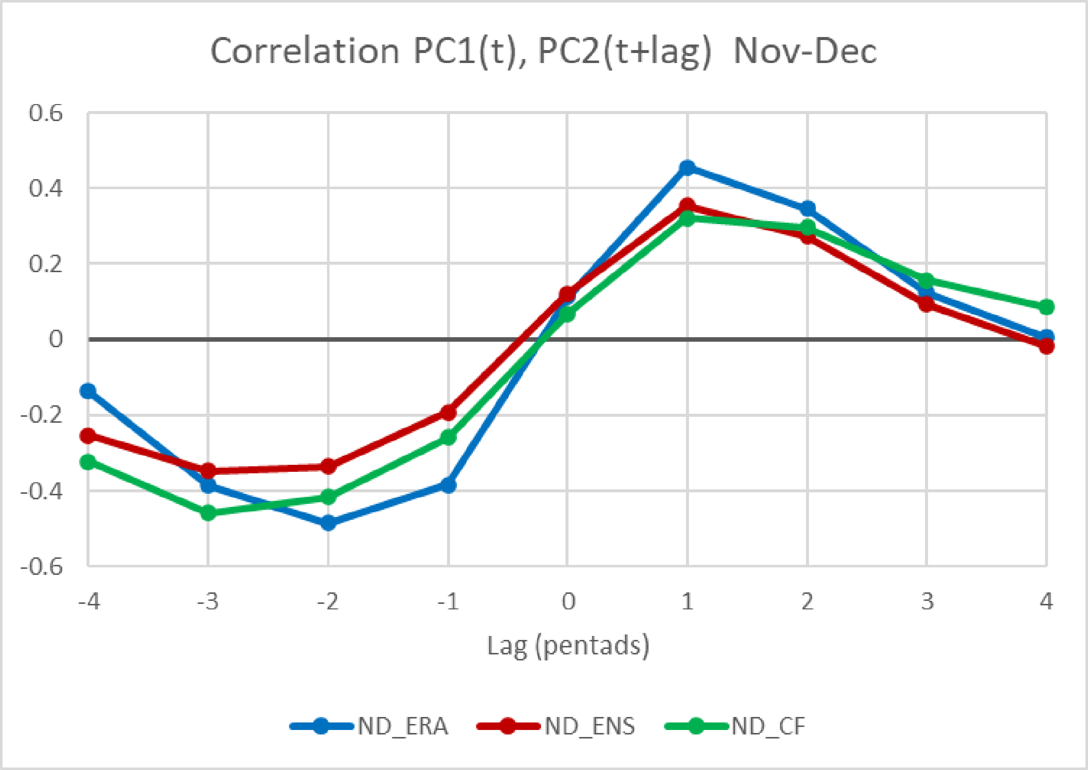
| | RMS amplitude of EOF ($W/m^2$) | Interannual variance(%) | Sub-seasonal variance (%) | Correl (Nino34, seas.mean PC) |
|---|---|---|---|---|
| **JF PC1** | 41.5 | 42.9 | 57.1 | 0.744 |
| **JF PC3** | 34.7 | 17.1 | 82.9 | -0.190 |
| **JF PC1 (ERA)** | 39.6 | 28.5 | 71.5 | 0.687 |
| **JF PC2 (ERA)** | 37.6 | 14.8 | 85.2 | 0.153 |

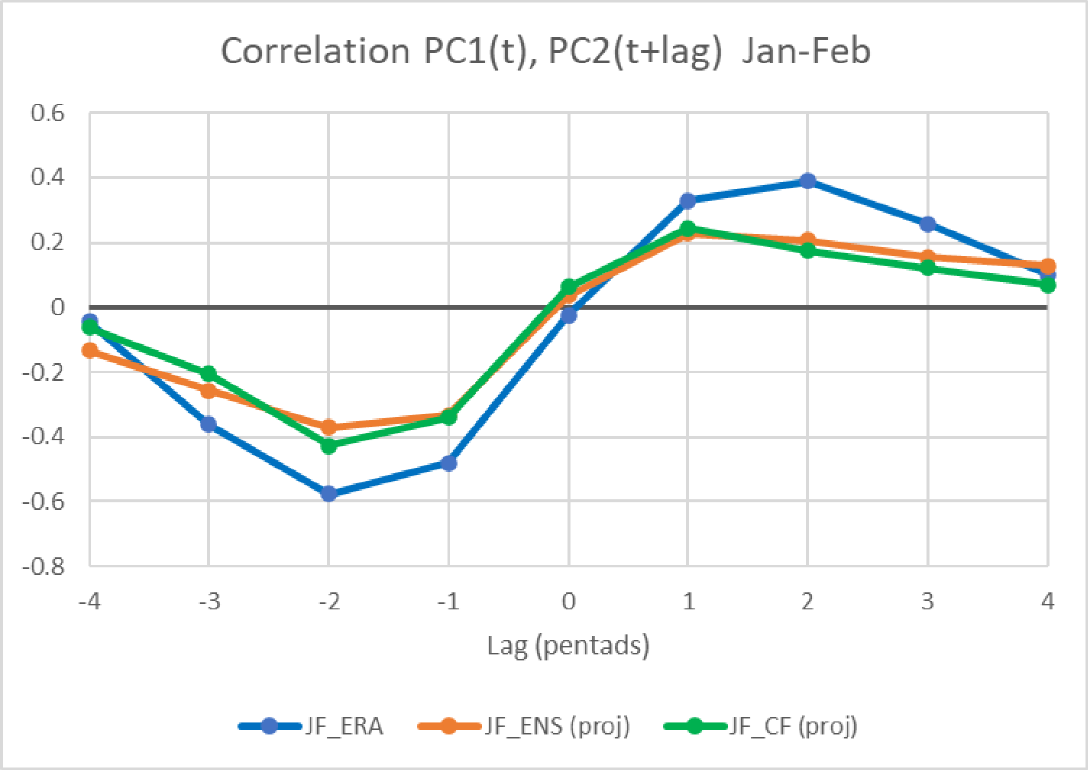
# Lag correlation of diabatic heating PCs, Jan-Feb (sub-seasonal)




Using projections of model anomalies on ERA EOFs 1 & 2, instead of model PCs 1 & 3, increases the amplitude of lagged correlations

# Lag correlation of diabatic heating PCs (sub-seasonal), full ENS vs CF only



# Summary of diabatic heating analysis

**ERA-5:**

- Two EOFs resembling the heating patterns in MJO phase 2 (EOF-1) and phase 3 (EOF-2) describe about 30-35% of the variance of spatially filtered diabatic heating in the Indian Ocean. The sub-seasonal components of PC-1 and PC-2 describe an eastward propagating heating anomaly, with PC2 lagging PC1 by ~ 2 pentads
- The proportion of interannual variance and the correlation of seasonal mean values with the Nino3.4 SST index are much larger for PC1 than for PC2; therefore, when the seasonal-mean signal is filtered out, the contribution of EOF2/PC2 is emphasized.

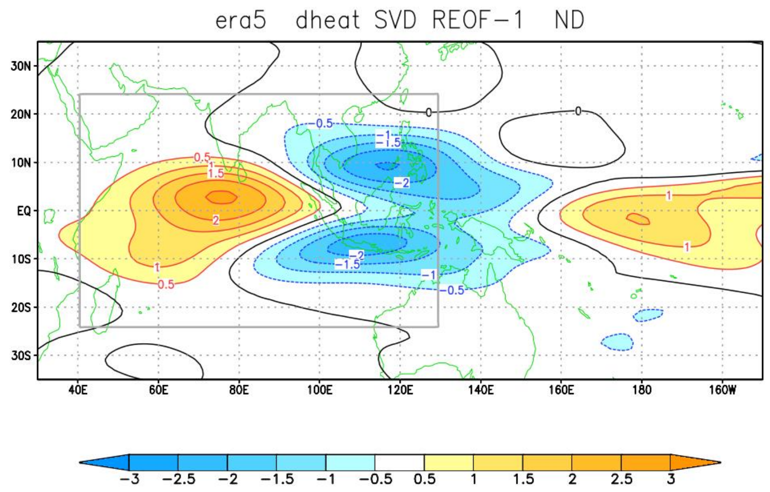
**Model ensembles:**

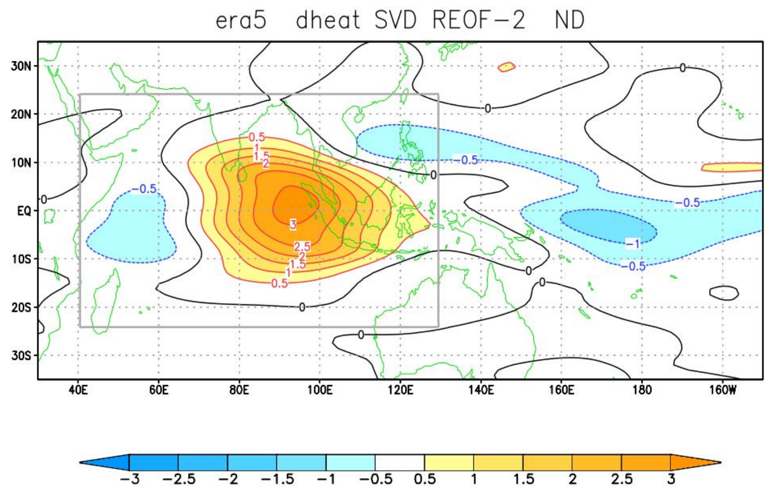
- In Nov-Dec, the patterns of the two leading EOFs of diabatic heating over the Indian Ocean show a very good agreement between model and re-analysis data, with only a slight under-estimation of the proportion of explained variance. In Jan-Feb, the order of EOFs 2 and 3 is inverted with respect to ERA; in model data, a meridional dipole becomes the second EOF.
- The weaker amplitude of lagged regressions of tropical heating suggest that the eastward propagation of the large-scale anomalies is less coherent in the model than in the real atmosphere. This finding also applies to the control forecasts, which have no stochastic perturbations.

# SVD analysis of diab. heating & gh 200-hPa: ND, ERA-5, lag: 4 pen.

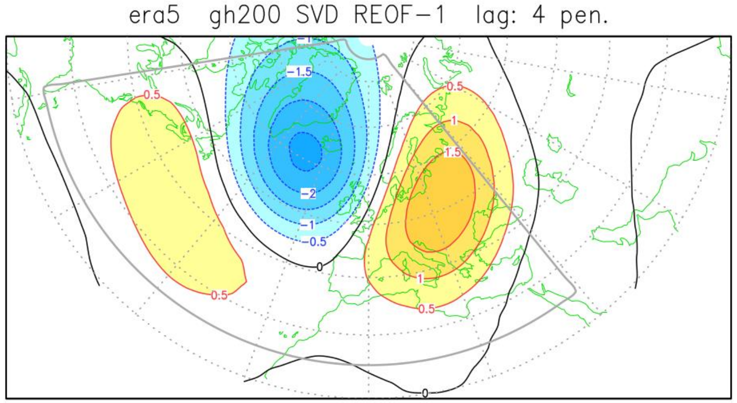
**cor = 0.310** **cor = 0.157**

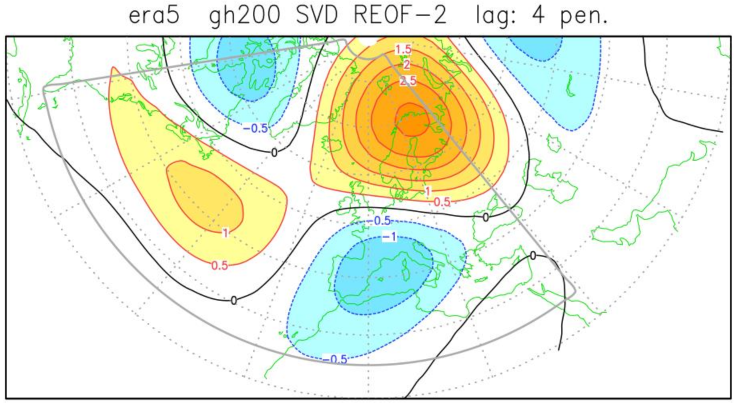
4 PCs
49% var.




7 PCs
80% var.



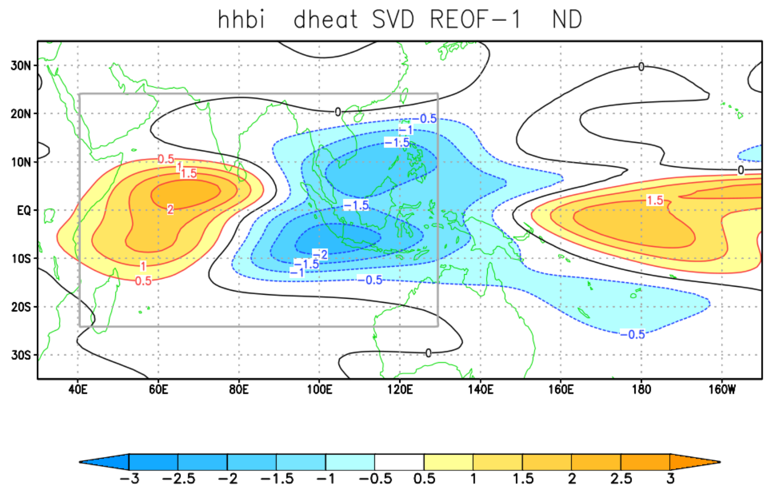



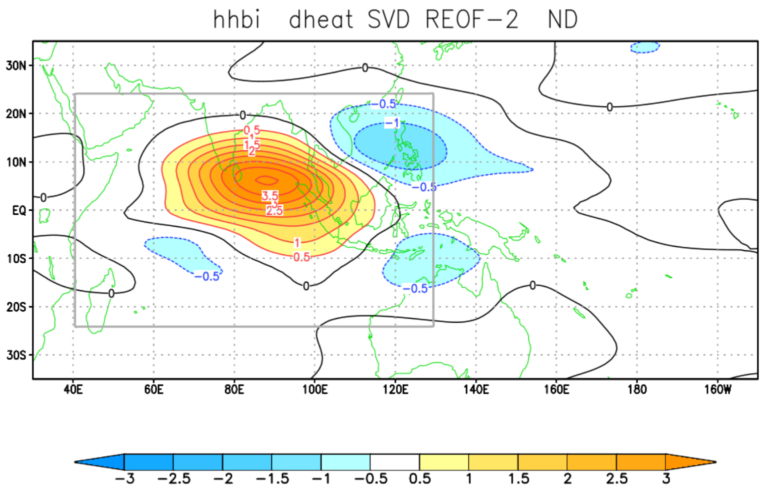
# SVD analysis of diab. heating & gh 200-hPa: ND, ENS (hhbi), lag: 3 pen.

**cor = 0.133**

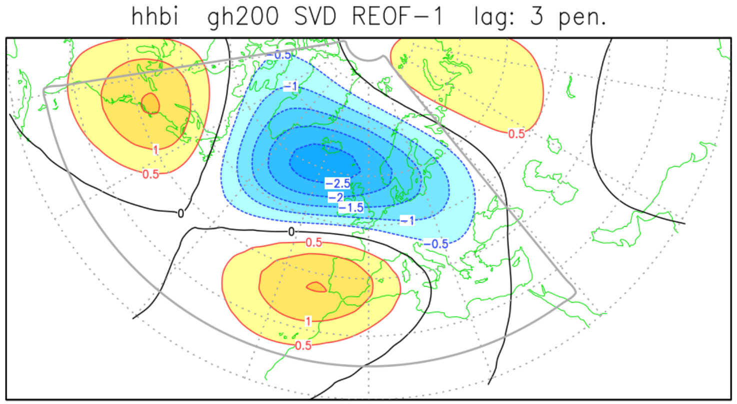
**cor = 0.097**

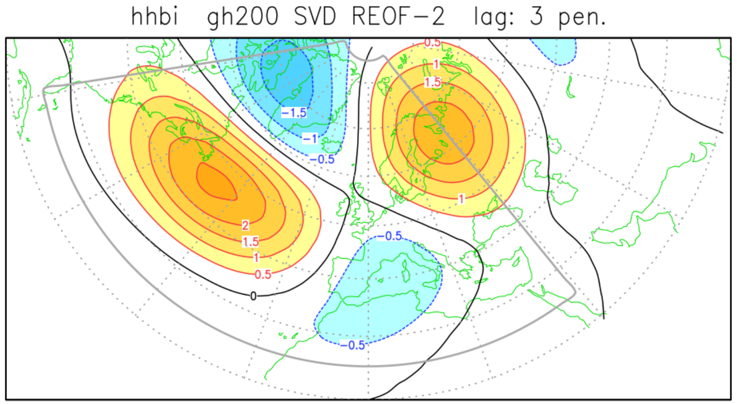
4 PCs
44% var.




7 PCs
78% var.



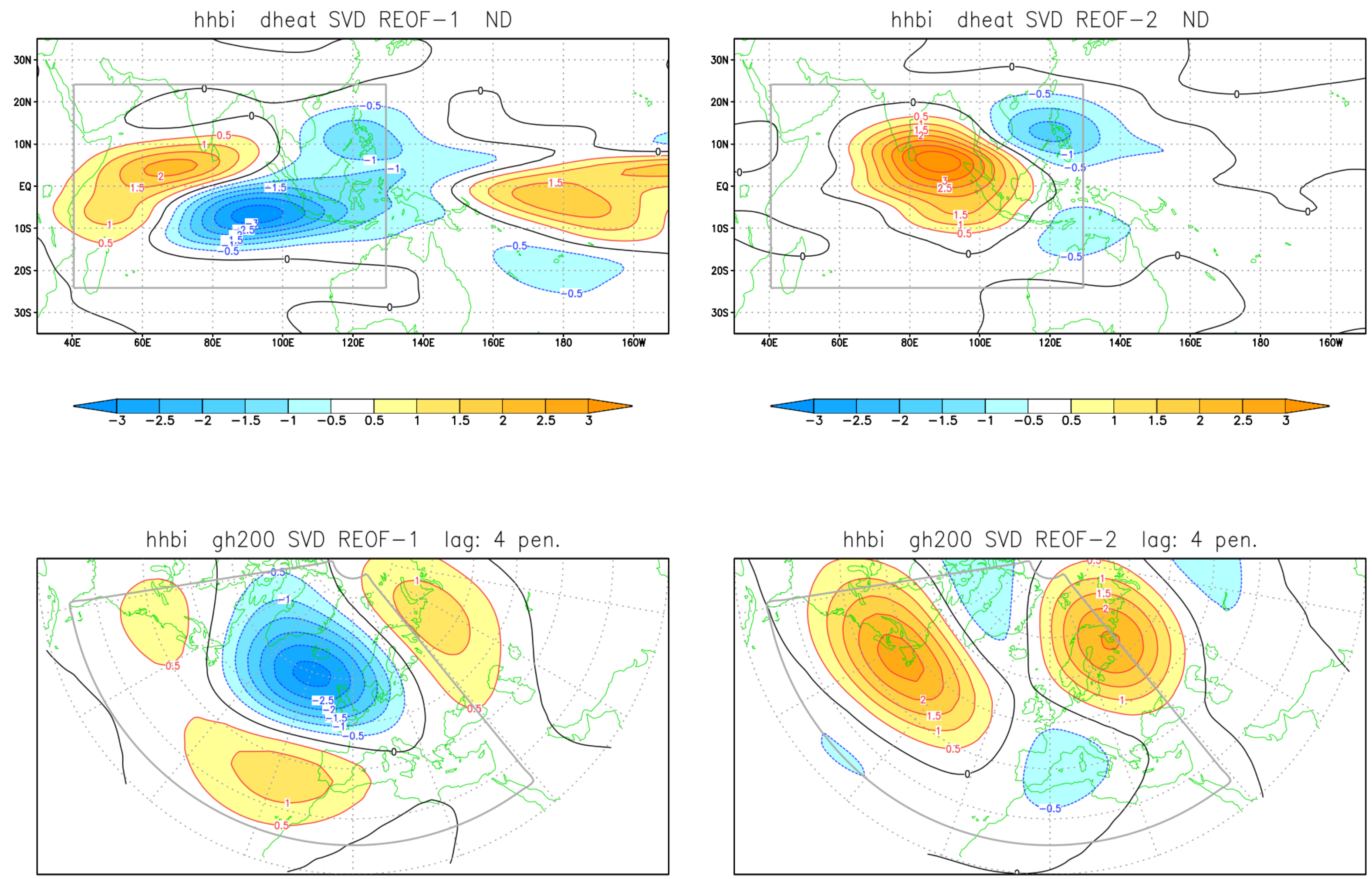



# SVD analysis of diab. heating & gh 200-hPa: ND, ENS (hhbi), lag: 4 pen.

**cor = 0.108** **cor = 0.123**

4 PCs
44% var.

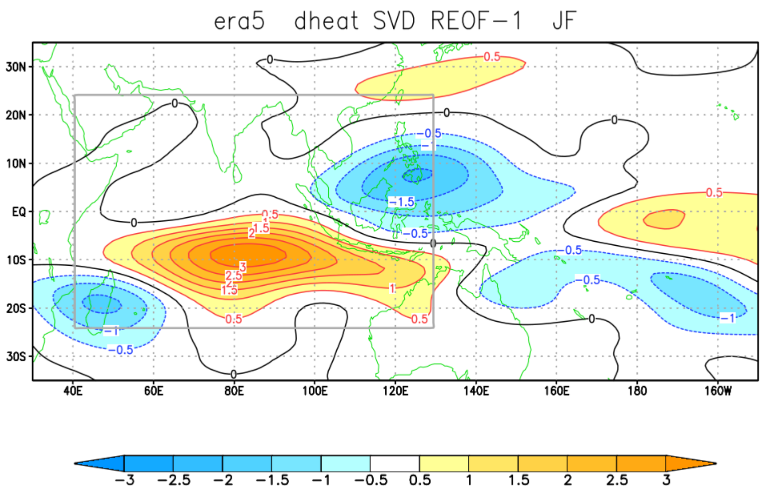
7 PCs
78% var.

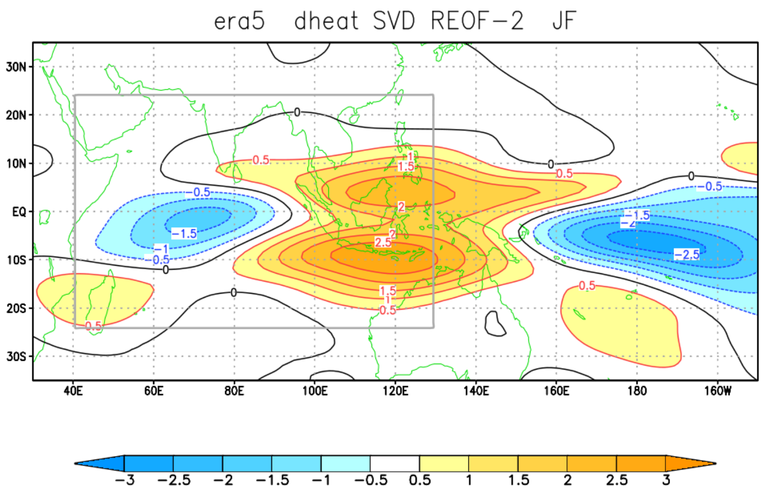


# SVD analysis of diab. heating & gh 200-hPa: JF, ERA-5, lag: 4 pen.

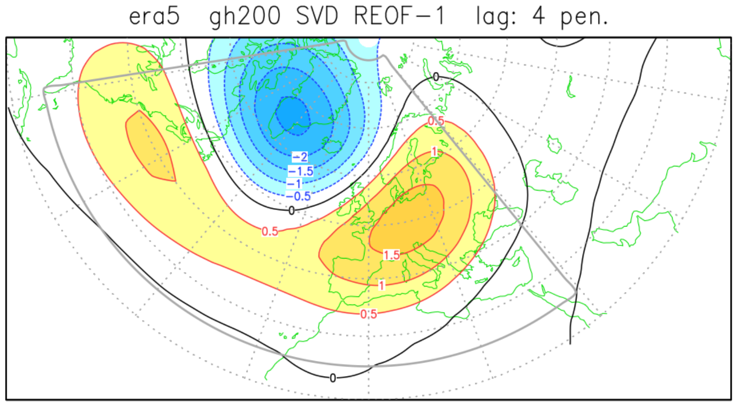
**cor = 0.341** **cor = 0.247**

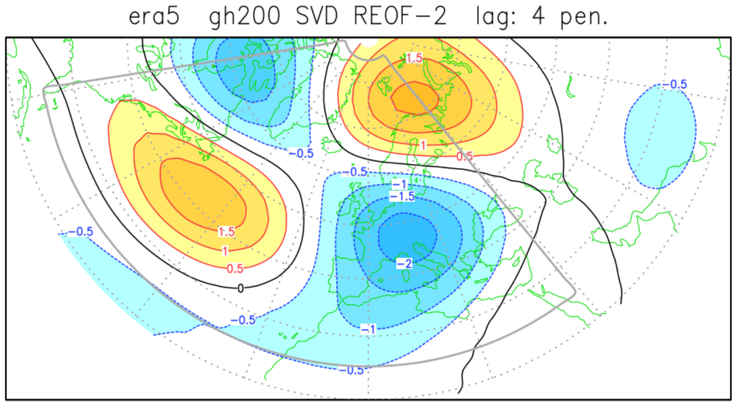
4 PCs
47% var.




7 PCs
81% var.

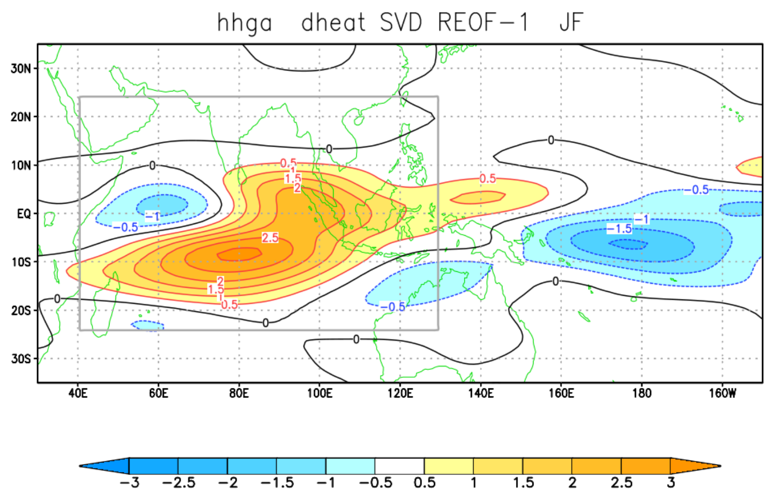


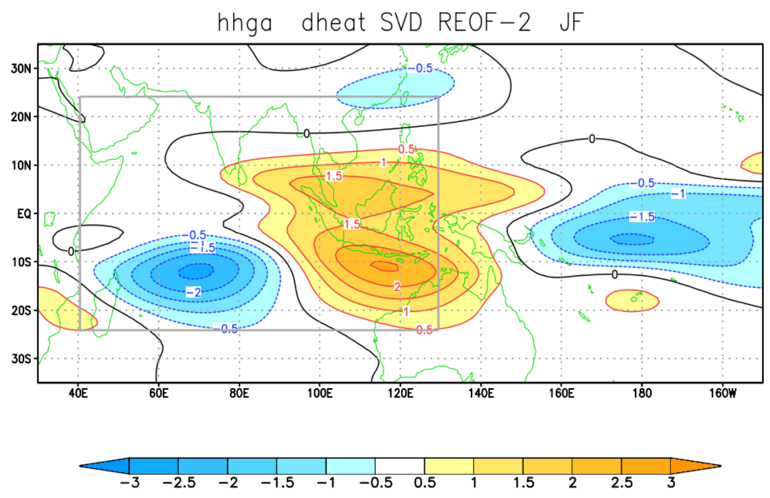



# SVD analysis of diab. heating & gh 200-hPa: JF, ENS (hhga), lag: 3 pen.

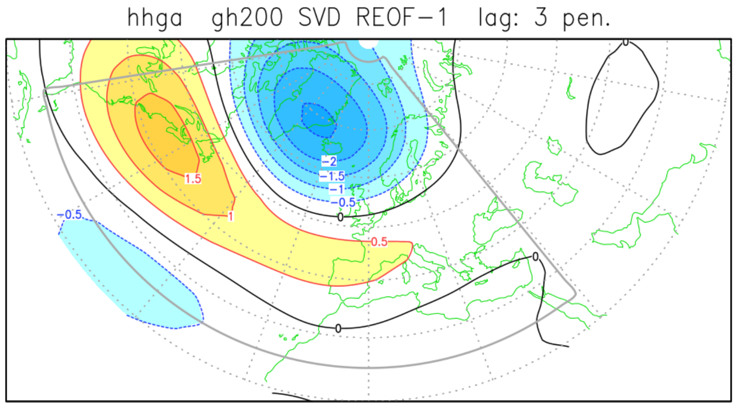
**cor = 0.174** **cor = 0.097**

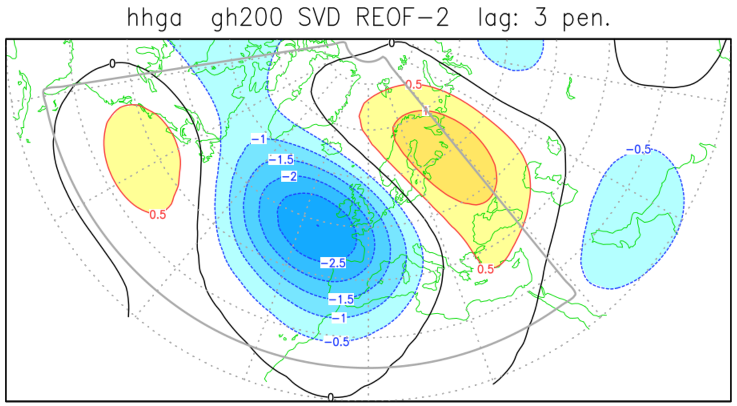
4 PCs
44% var.




7 PCs
81% var.



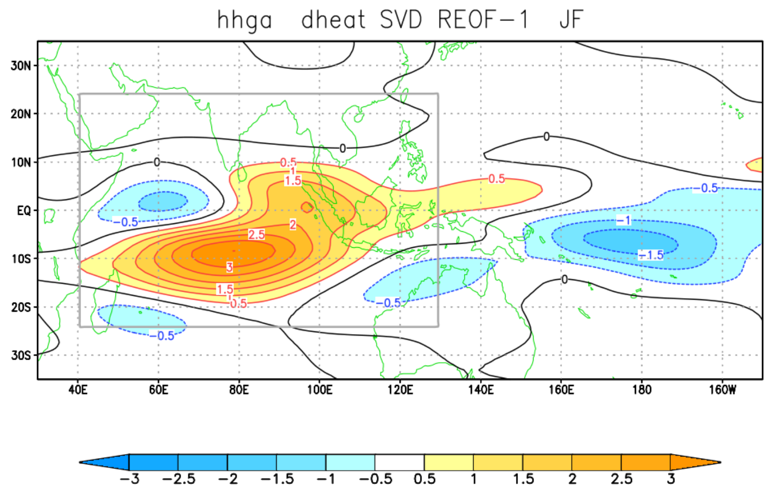



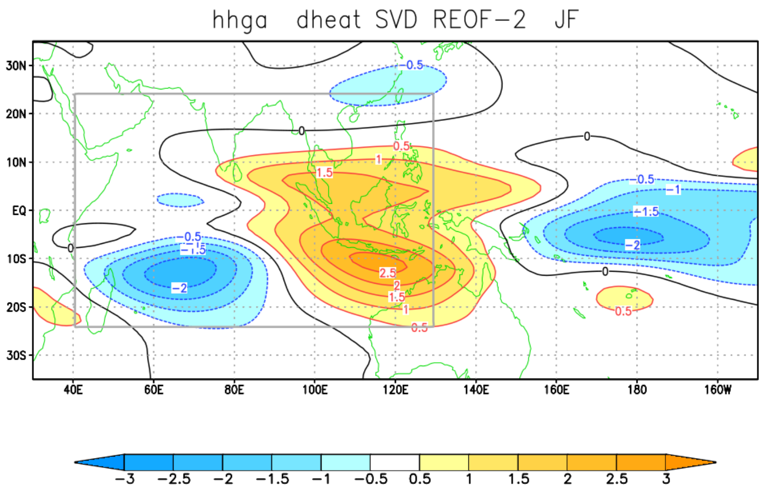
# SVD analysis of diab. heating & gh 200-hPa: JF, ENS (hhga), lag: 4 pen.

**cor = 0.154**

**cor = 0.123**

4 PCs
44% var.

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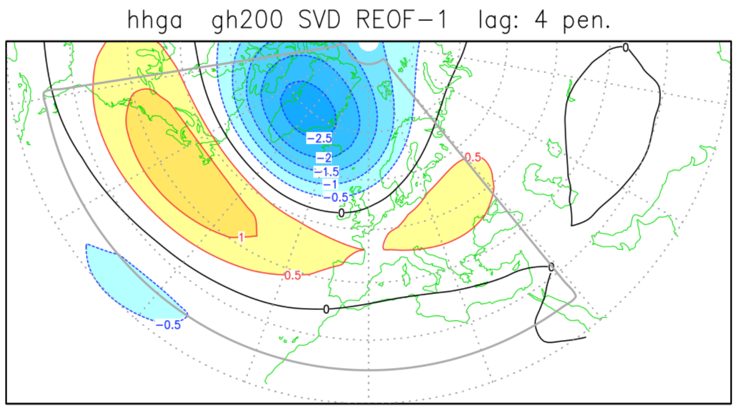


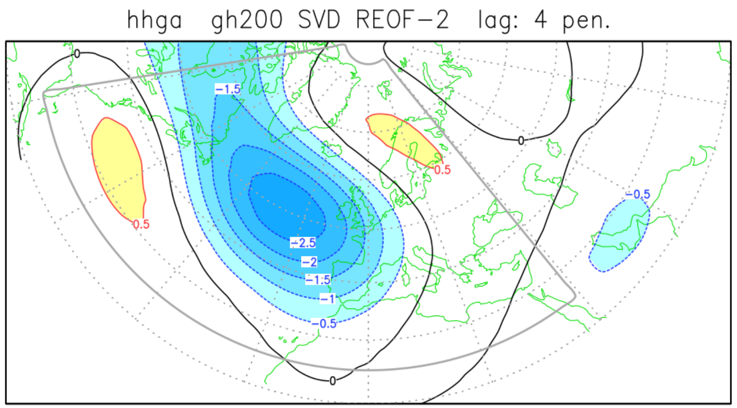

# Summary of tropical-North Atlantic teleconnections (SVD analysis)

- In Nov-Dec, heating patterns similar to the 1st and 2nd EOFs patterns are linearly correlated with 200-hPa height anomalies resembling a positive NAO and a Scandinavian blocking pattern respectively, with lag of 3-4 pentads. The signal coming from heating EOF-1 (~ MJO phase 2) has a rather strong persistence due to the large inter-annual component, which may be filtered out in sub-seasonal analyses.
- In the model, the co-varying spatial patterns of heating and height anomalies are reasonably well reproduced, but the strength of the correlation is much lower, especially for the NAO signal. The biases affecting the eastern Indian Ocean heating in autumn affect the SVD patterns at lags longer than 3 pentads.
- In Jan-Feb, the position of the heating co-varying with the NAO+ and Scan. Blocking moves to the east, so that the NAO+ "forcing" is more similar to a MJO phase 3 (EOF-2).
- The ensembles reproduce the NAO teleconnection patterns reasonably well, but the teleconnection with heating from the Maritime Continents is quite different from re-analysis. Again the correlations are much weaker than in ERA, by about a factor of 2.
- I.C. perturbations and stochastic physics are not applied over the extratropics in these ensembles, therefore extratropical perturbations do not appear to be the cause of weakened teleconnections in the ECMWF sub-seasonal forecasts.