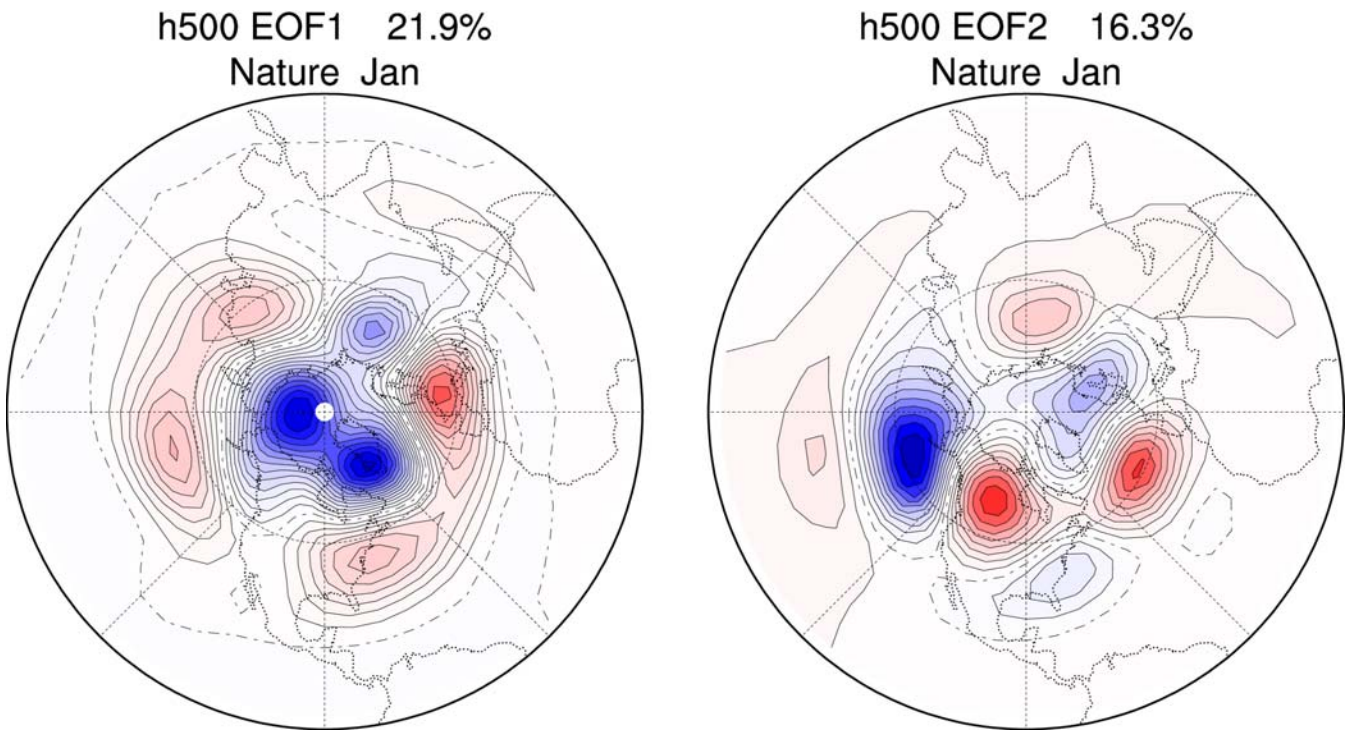
# PDFs of Planetary Wave States

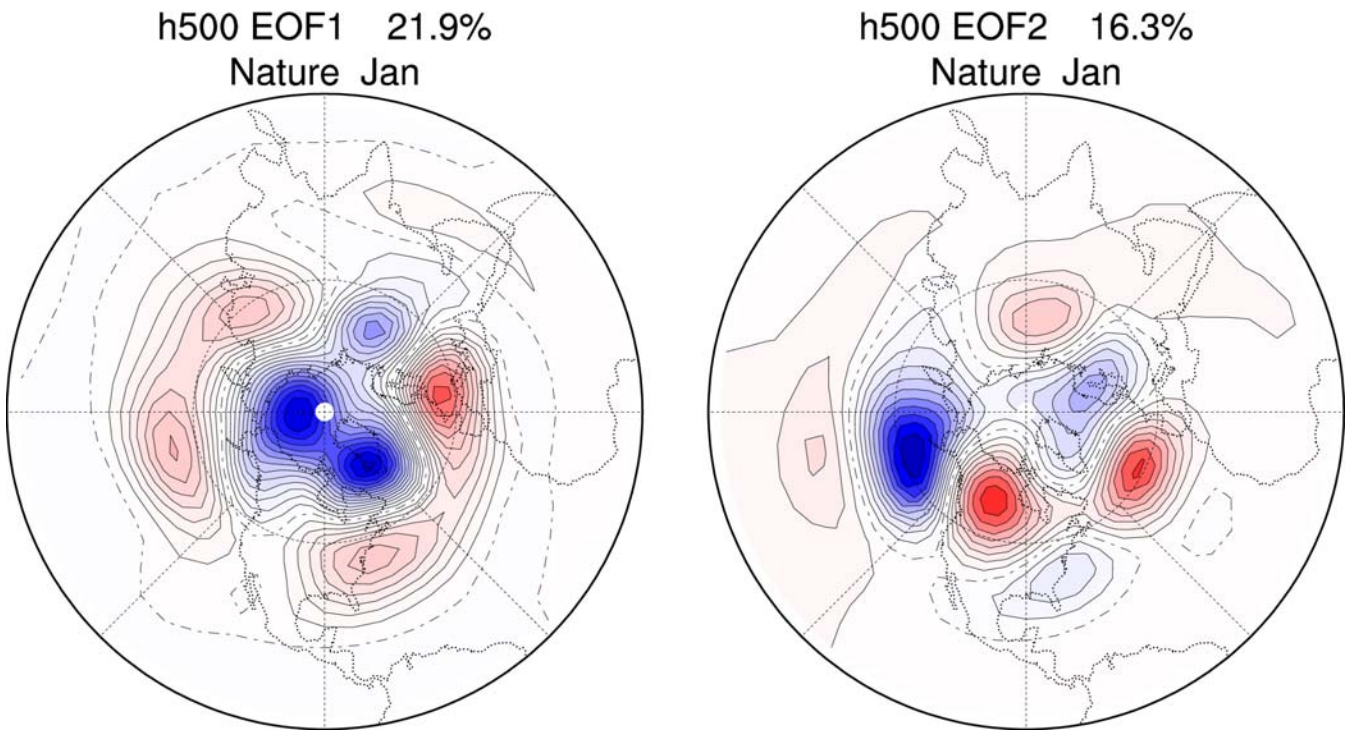
*Grant Branstator*



# PDFs of Planetary Wave States

## Using stochastic parameterization to learn about intrinsic patterns of variability

*Grant Branstator*

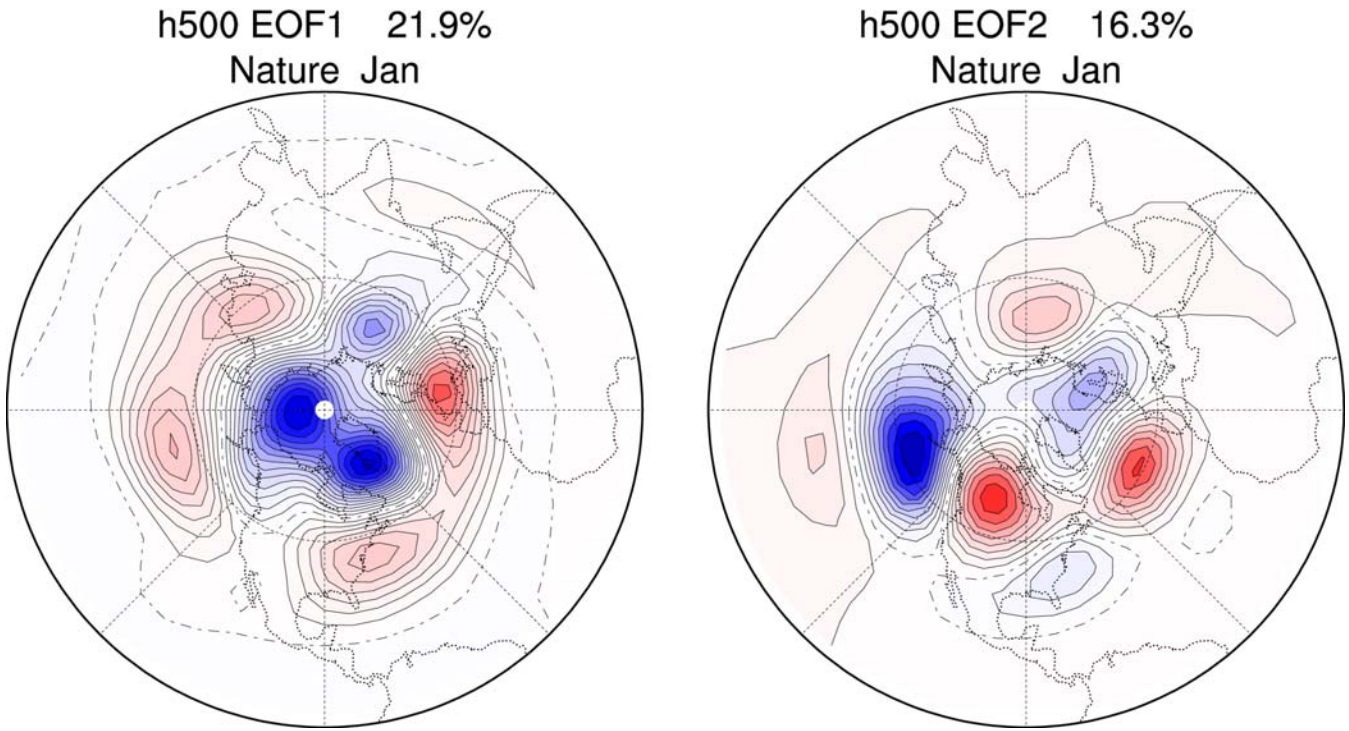


# PDFs of Planetary Wave States

## Using stochastic parameterization to learn about intrinsic patterns of variability

*Grant Branstator*

*Frank Selten, Claudia Tebaldi, Doug Nychka, Judith Berner*



# Part I

# Stochastic representation of missing dynamical processes

# Dutch Challenge Project

Frank Selten  KNMI

Henk Dijkstra  Univ. Utrecht & CSU

CCSM1.4/T31/x3

Bette Otto-Bliesner

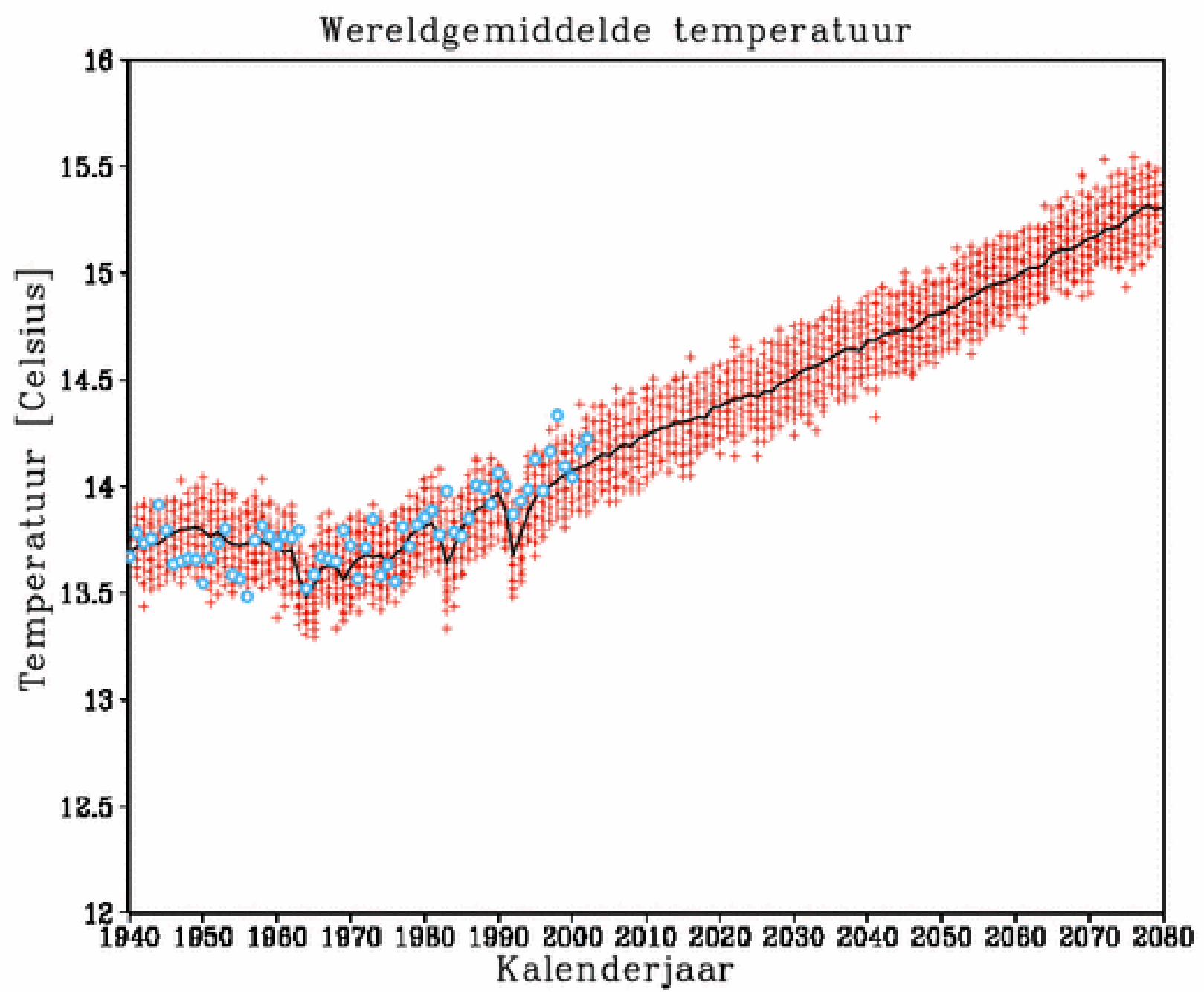
Caspar Ammann

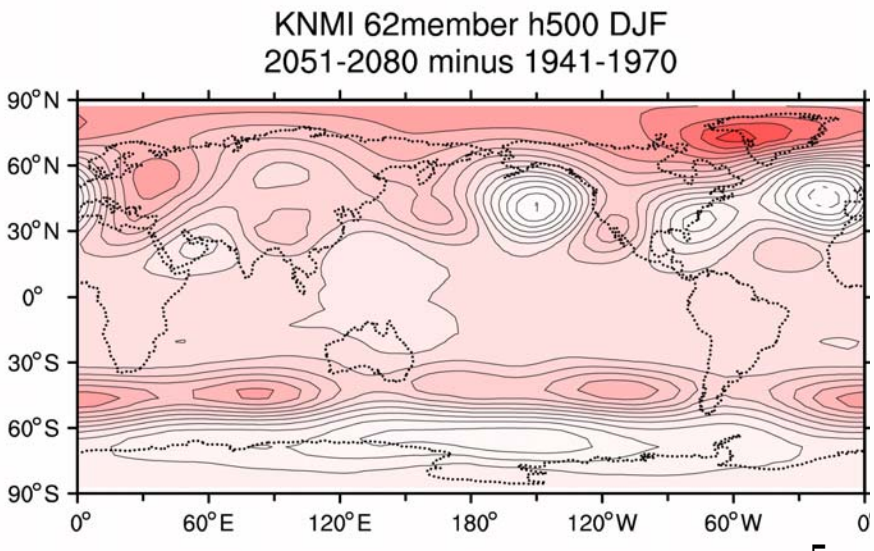
1940-2080 scenario

1940-2000: prescribed GHG, sulphate aerosols, solar radiation, volcanic aerosols

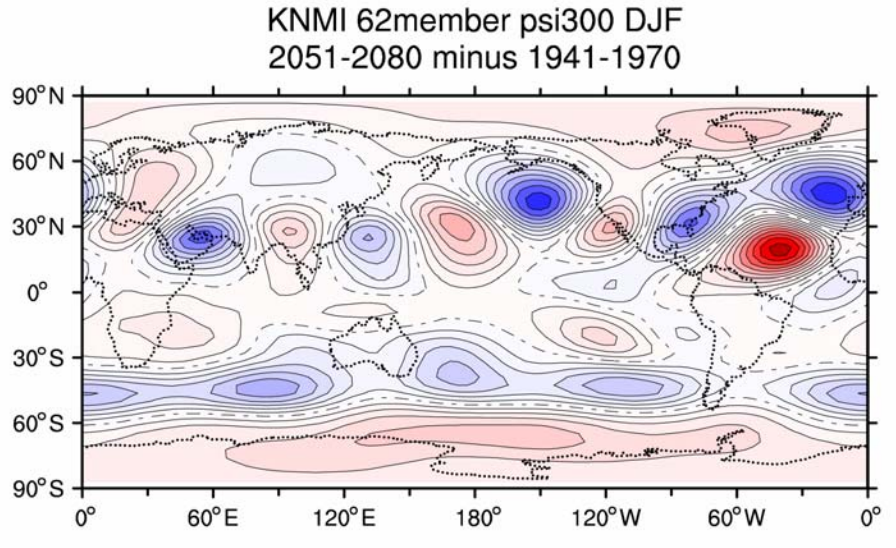
2001-2080: business as usual GHG

→ 62 member ensemble differing only in initial state

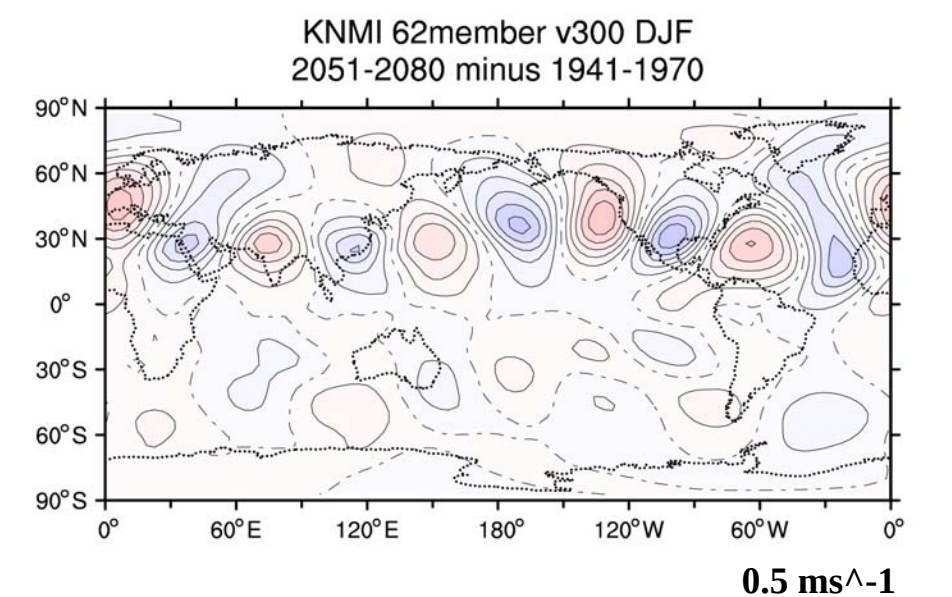

Wereldgemiddelde temperatuur
Temperatuur [Celsius]
16
15.5
15
14.5
14
13.5
13
12.5
12
1940 1950 1960 1970 1980 1990 2000 2010 2020 2030 2040 2050 2060 2070 2080
Kalenderjaar



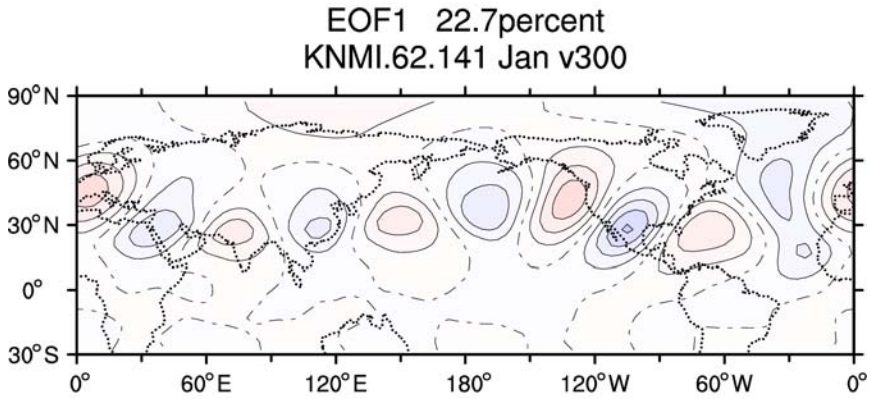

**5 m**

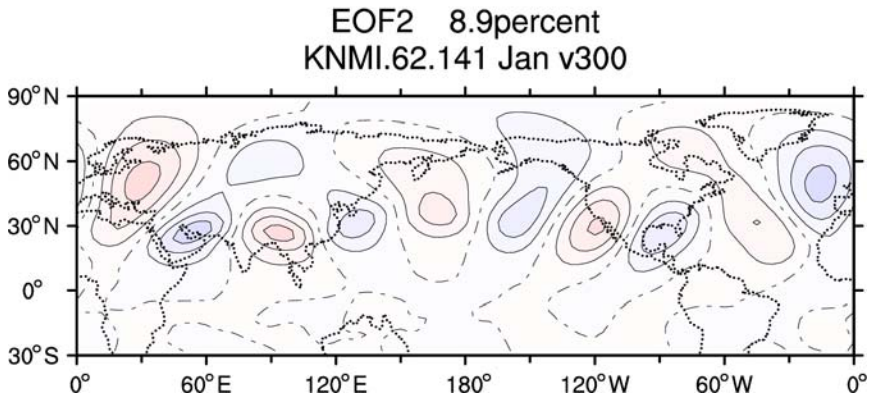


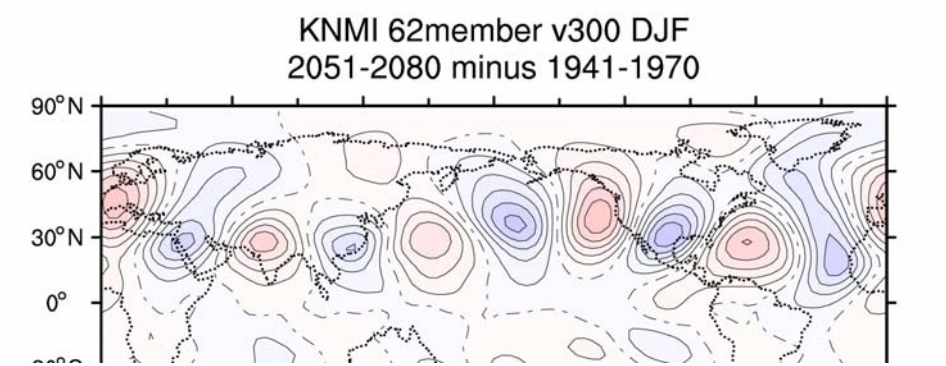

**5x10^5 m^2s^-1**

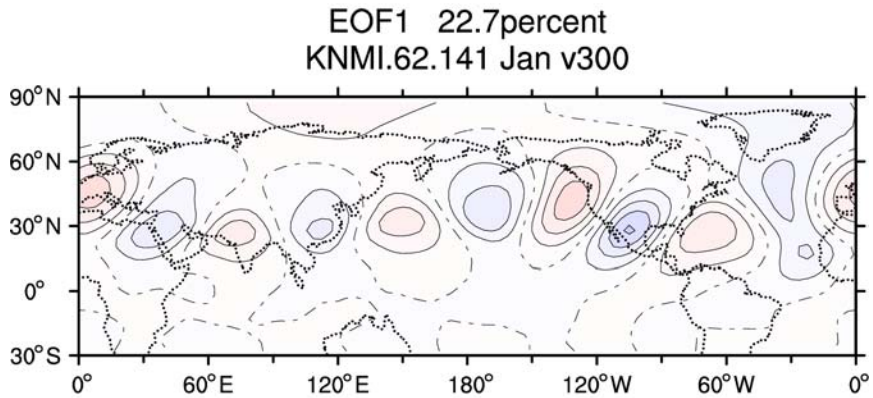


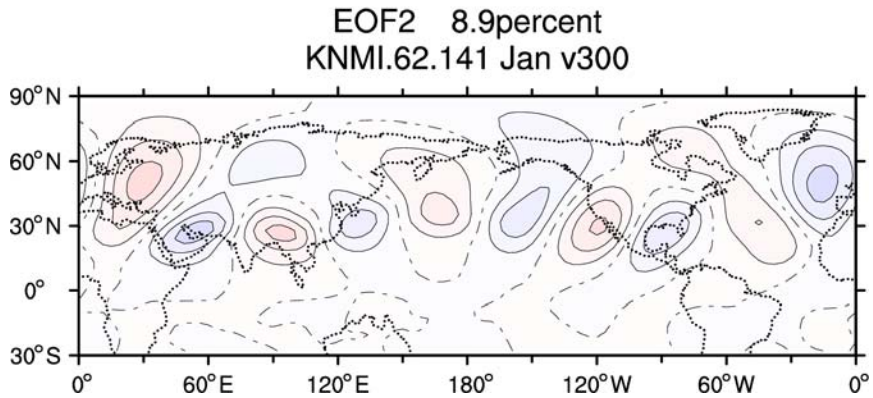

**0.5 ms^-1**

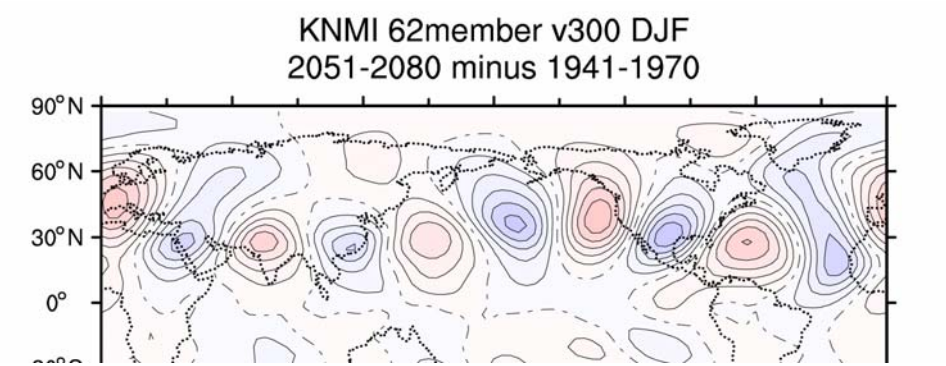

EOF1 22.7percent
KNMI.62.141 Jan v300
90°N
60°N
30°N
0°
30°S
0°
60°E
120°E
180°
120°W
60°W
0°

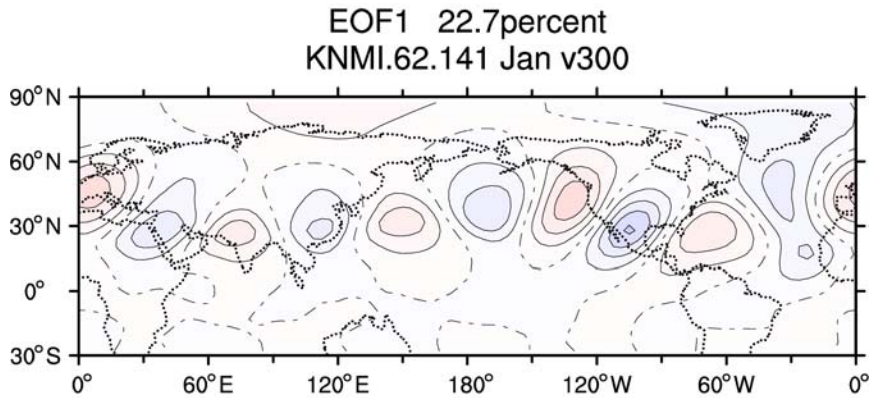

EOF2 8.9percent
KNMI.62.141 Jan v300
90°N
60°N
30°N
0°
30°S
0°
60°E
120°E
180°
120°W
60°W
0°


KNMI 62member v300 DJF
2051-2080 minus 1941-1970
90°N
60°N
30°N
0°

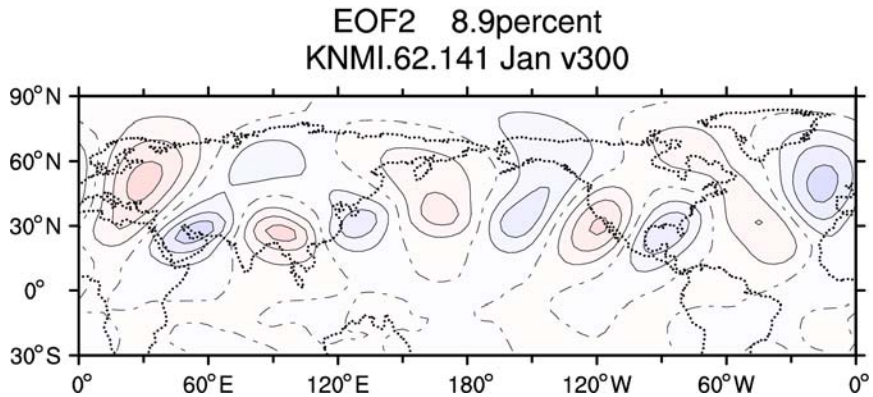

EOF1 22.7percent
KNMI.62.141 Jan v300
90°N
60°N
30°N
0°
30°S
0°
60°E
120°E
180°
120°W
60°W
0°


EOF2 8.9percent
KNMI.62.141 Jan v300
90°N
60°N
30°N
0°
30°S
0°
60°E
120°E
180°
120°W
60°W
0°




**“Circumglobal Waveguide Pattern”**



# Why does a system have natural patterns of variability? (Possibility I)

$$\frac{\partial \varsigma}{\partial t} = -\vec{v}_{\psi} \cdot \nabla(\varsigma + f) - \ldots$$

$$() = \frac{1}{T}\int_{0}^{T} ()dt + ()'$$

$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_{\psi} \cdot \nabla(\bar{\varsigma} + f) - \bar{\vec{v}}_{\psi} \cdot \nabla\varsigma' - \vec{v}'_{\psi} \cdot \nabla\bar{\varsigma} - \vec{v}'_{\psi} \cdot \nabla\varsigma' \ldots$$

$$\bar{\vec{v}}_{\psi} \cdot \nabla(\bar{\varsigma} + f) = -\overline{\vec{v}'_{\psi} \cdot \nabla\varsigma'} + \ldots$$

$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_{\psi} \cdot \nabla\varsigma' - \vec{v}'_{\psi} \cdot \nabla\bar{\varsigma} - (\vec{v}'_{\psi} \cdot \nabla\varsigma' - \overline{\vec{v}'_{\psi} \cdot \nabla\varsigma'}) \ldots$$

$$= -\bar{\vec{v}}_{\psi} \cdot \nabla\varsigma' - \vec{v}'_{\psi} \cdot \nabla\bar{\varsigma} + damping + noise \ldots$$

$$\frac{\partial \varsigma}{\partial t} = -\vec{v}_\psi \cdot \nabla(\varsigma + f) - \ldots$$

$$() = \frac{1}{T}\int_0^T ()dt + ()'$$

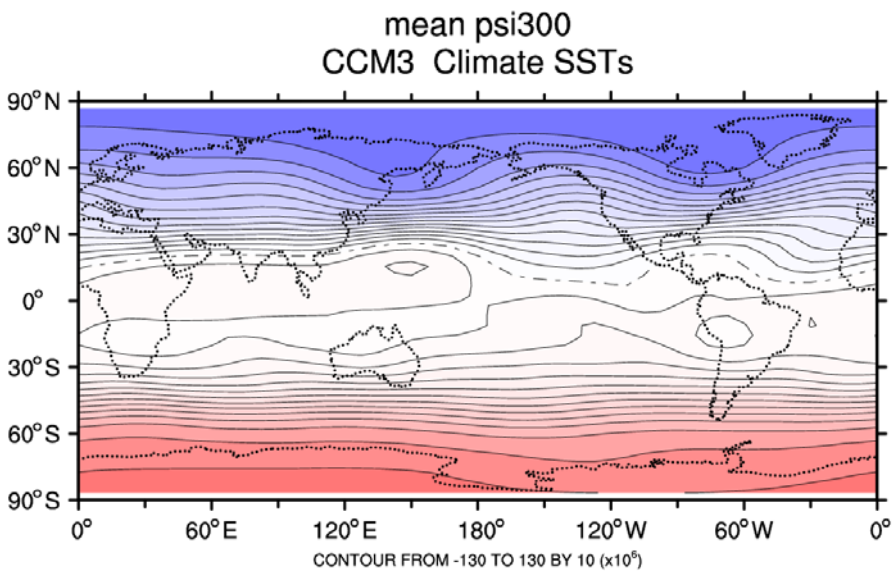
$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_\psi \cdot \nabla(\bar{\varsigma} + f) - \bar{\vec{v}}_\psi \cdot \nabla\varsigma' - \vec{v}'_\psi \cdot \nabla\bar{\varsigma} - \vec{v}'_\psi \cdot \nabla\varsigma' \ldots$$

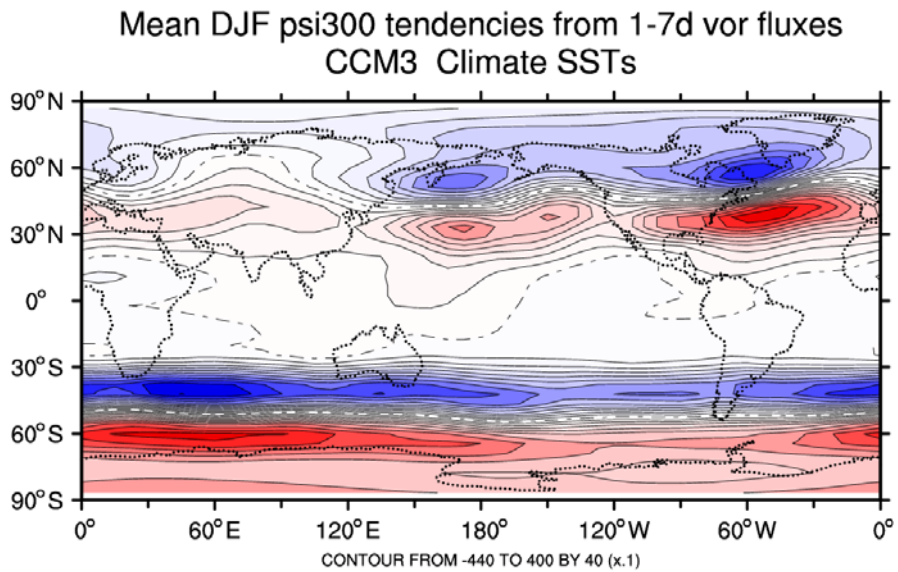
$$\bar{\vec{v}}_\psi \cdot \nabla(\bar{\varsigma} + f) = -\overline{\vec{v}'_\psi \cdot \nabla\varsigma'} + \ldots$$

$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_\psi \cdot \nabla\varsigma' - \vec{v}'_\psi \cdot \nabla\bar{\varsigma} - (\vec{v}'_\psi \cdot \nabla\varsigma' - \overline{\vec{v}'_\psi \cdot \nabla\varsigma'}) \ldots$$

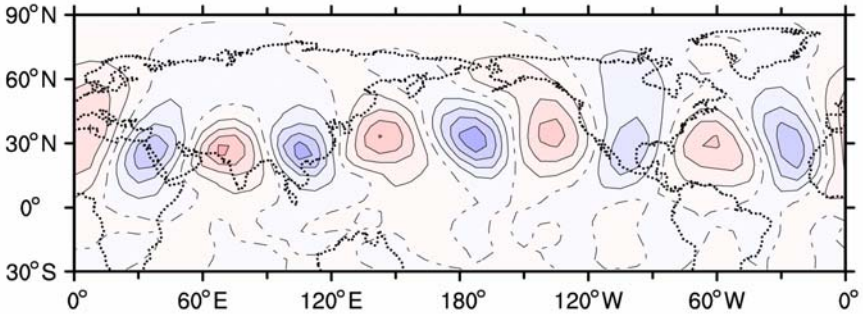
$$= -\bar{\vec{v}}_\psi \cdot \nabla\varsigma' - \vec{v}'_\psi \cdot \nabla\bar{\varsigma} + damping + noise \ldots$$

$$-\nabla^{-2}\overline{(\vec{v}' \cdot \nabla\varsigma')}$$

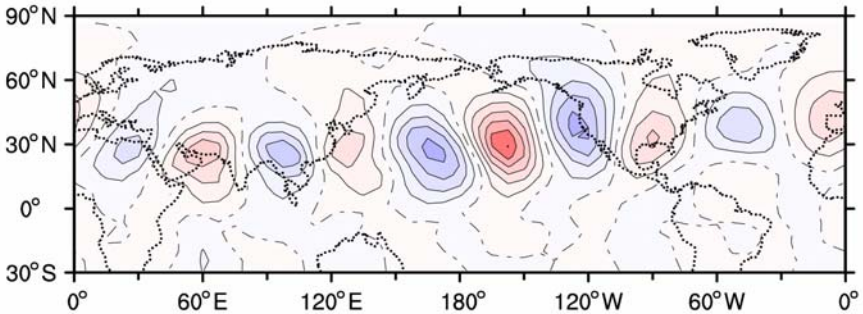


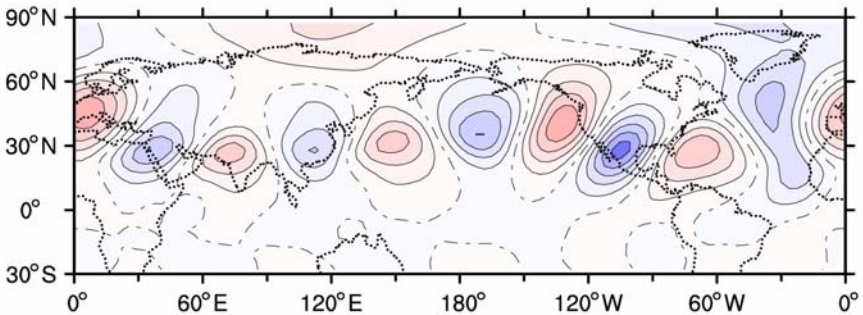
vEOF1 11.2 %
Stochastic Linear with First 30yr Basic State



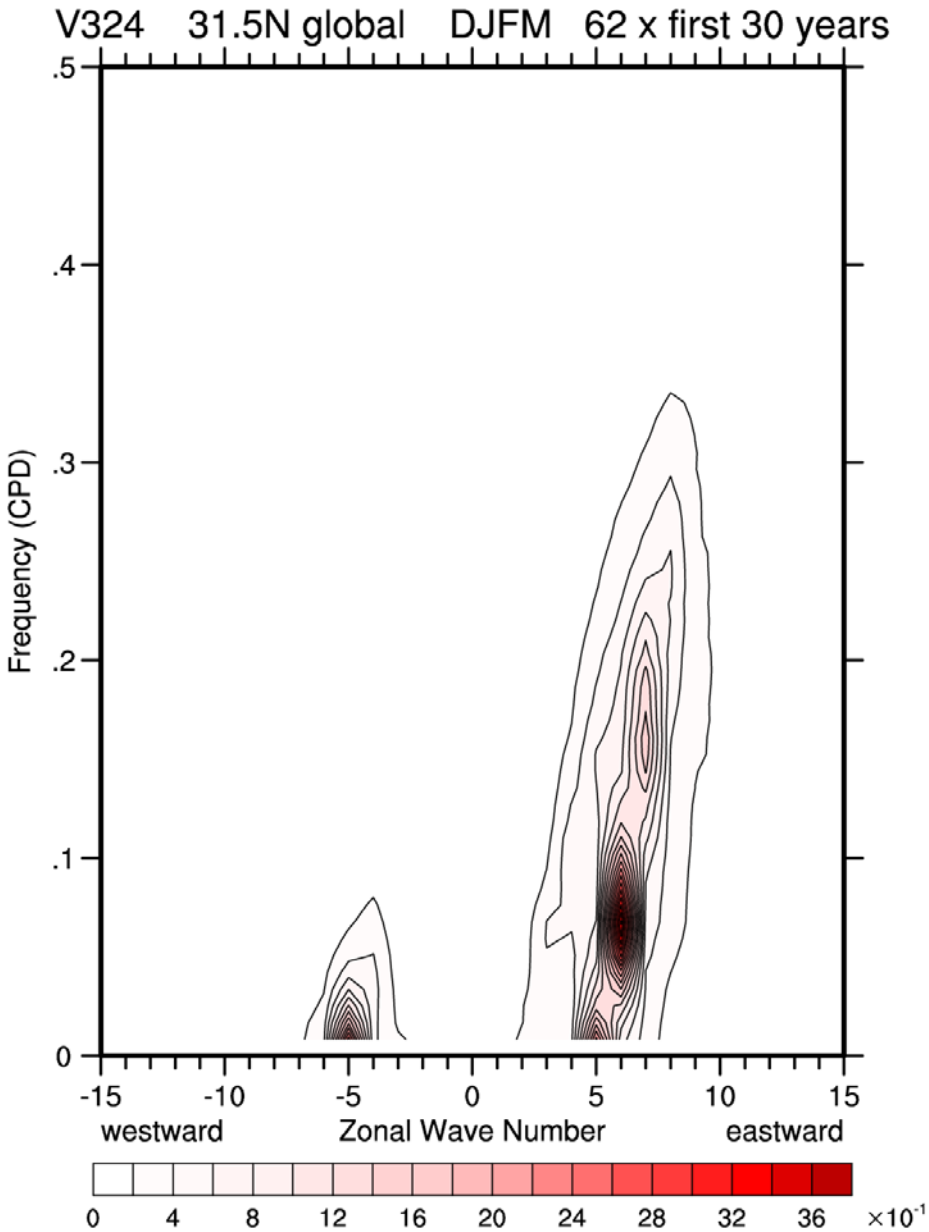

vEOF2 8.3 %
Stochastic Linear with First 30yr Basic State



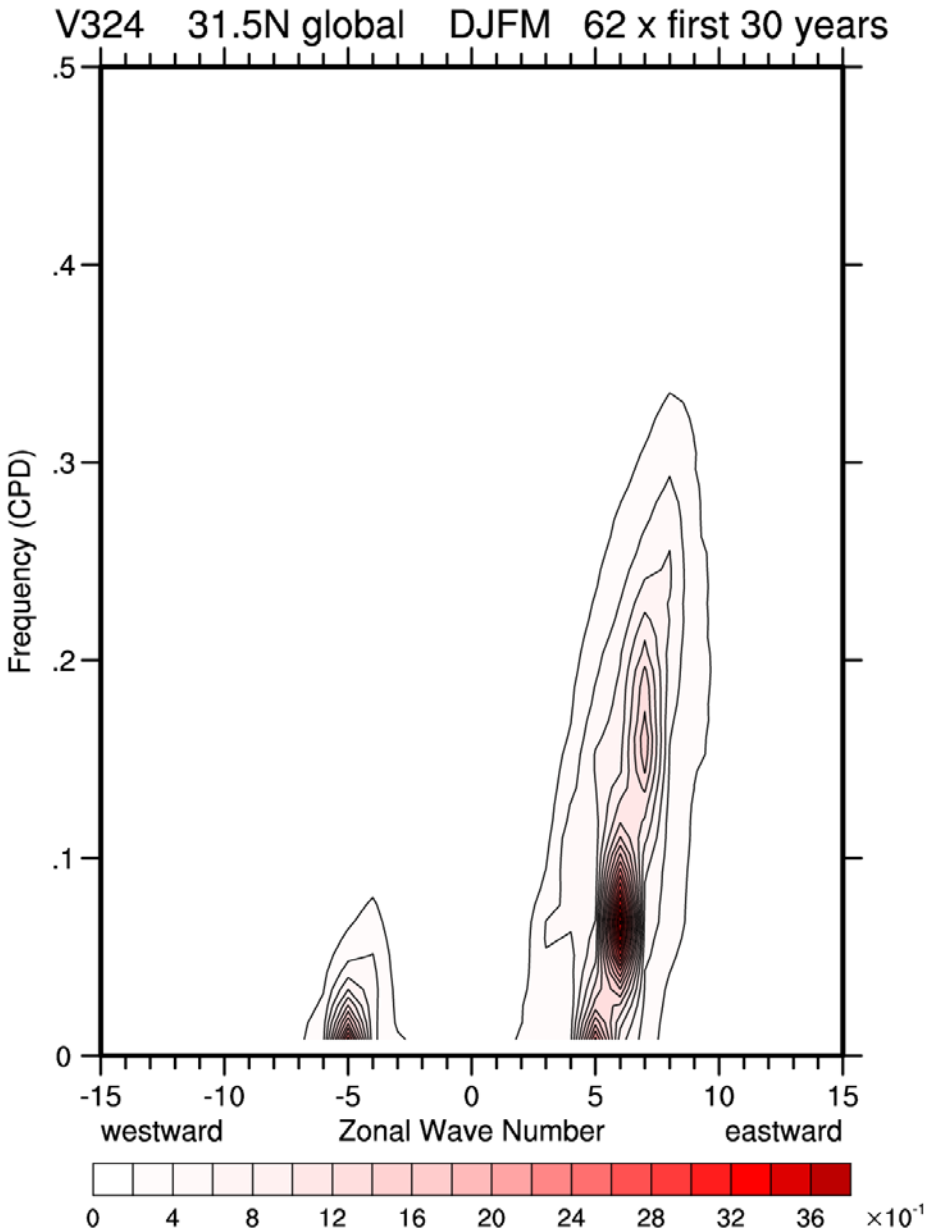

vEOF1 21.8 %
KNMI Jan



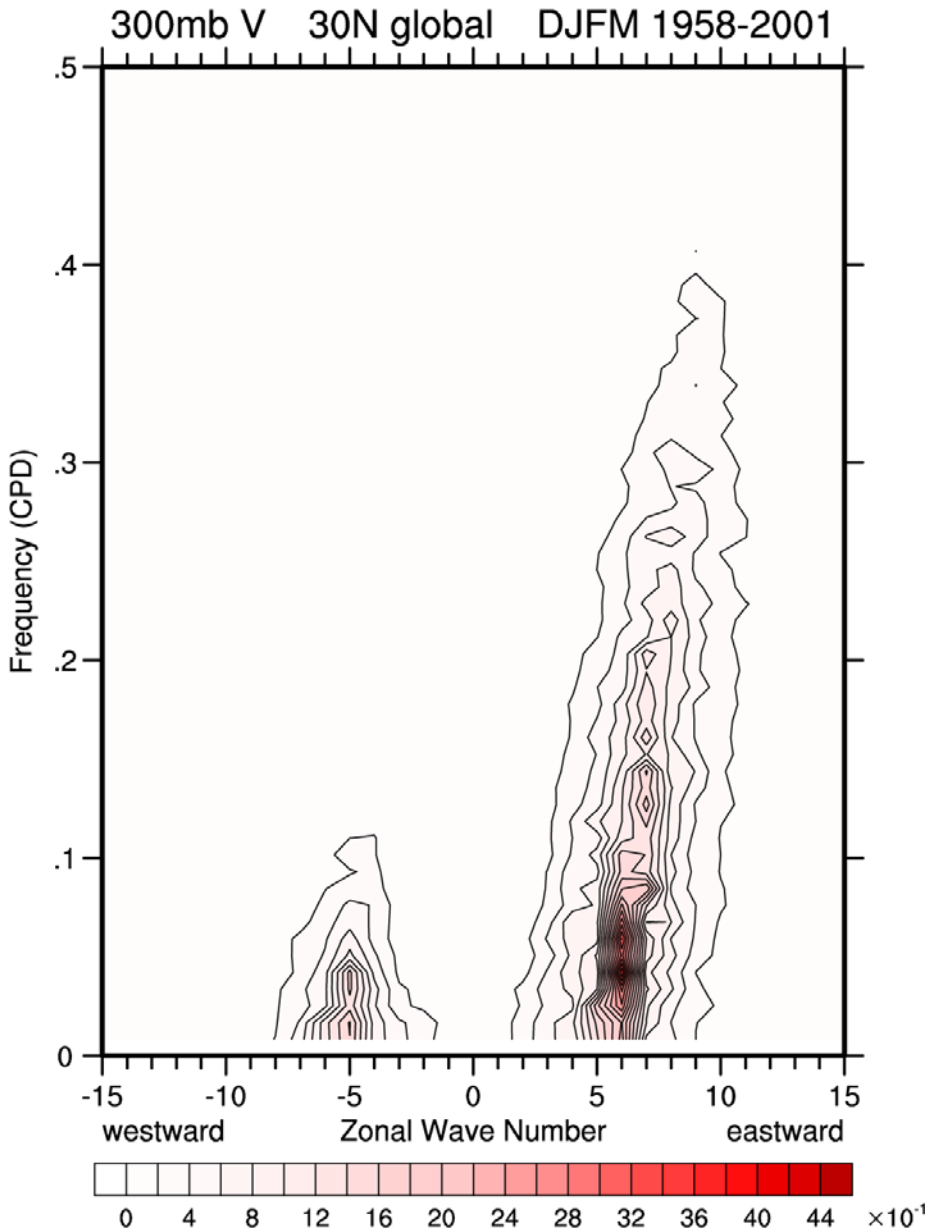
# CCSM1.4


V324 31.5N global DJFM 62 x first 30 years
.5
.4
.3
.2
.1
0
Frequency (CPD)
-15
-10
-5
0
5
10
15
westward
Zonal Wave Number
eastward
0
4
8
12
16
20
24
28
32
36
×10-1

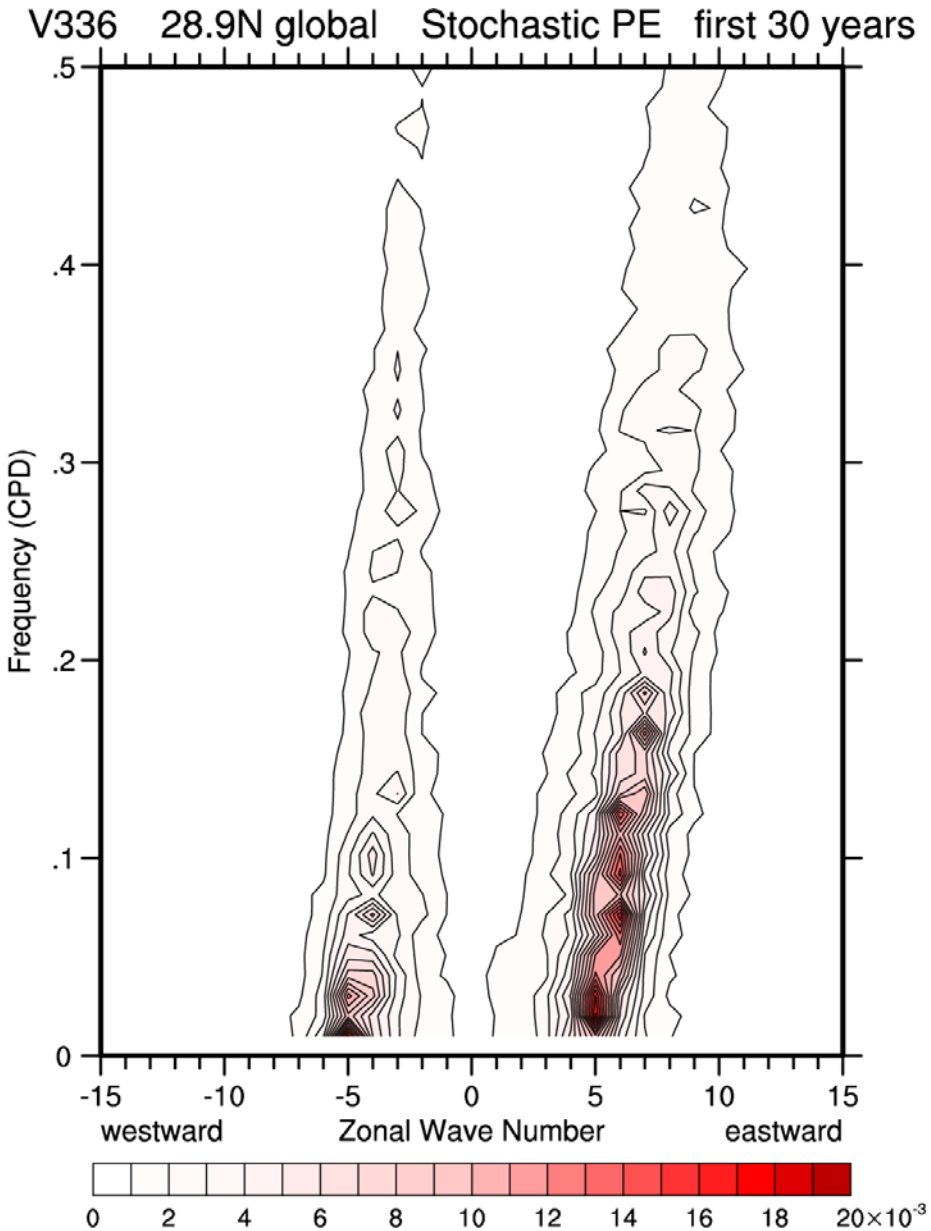
CCSM1.4



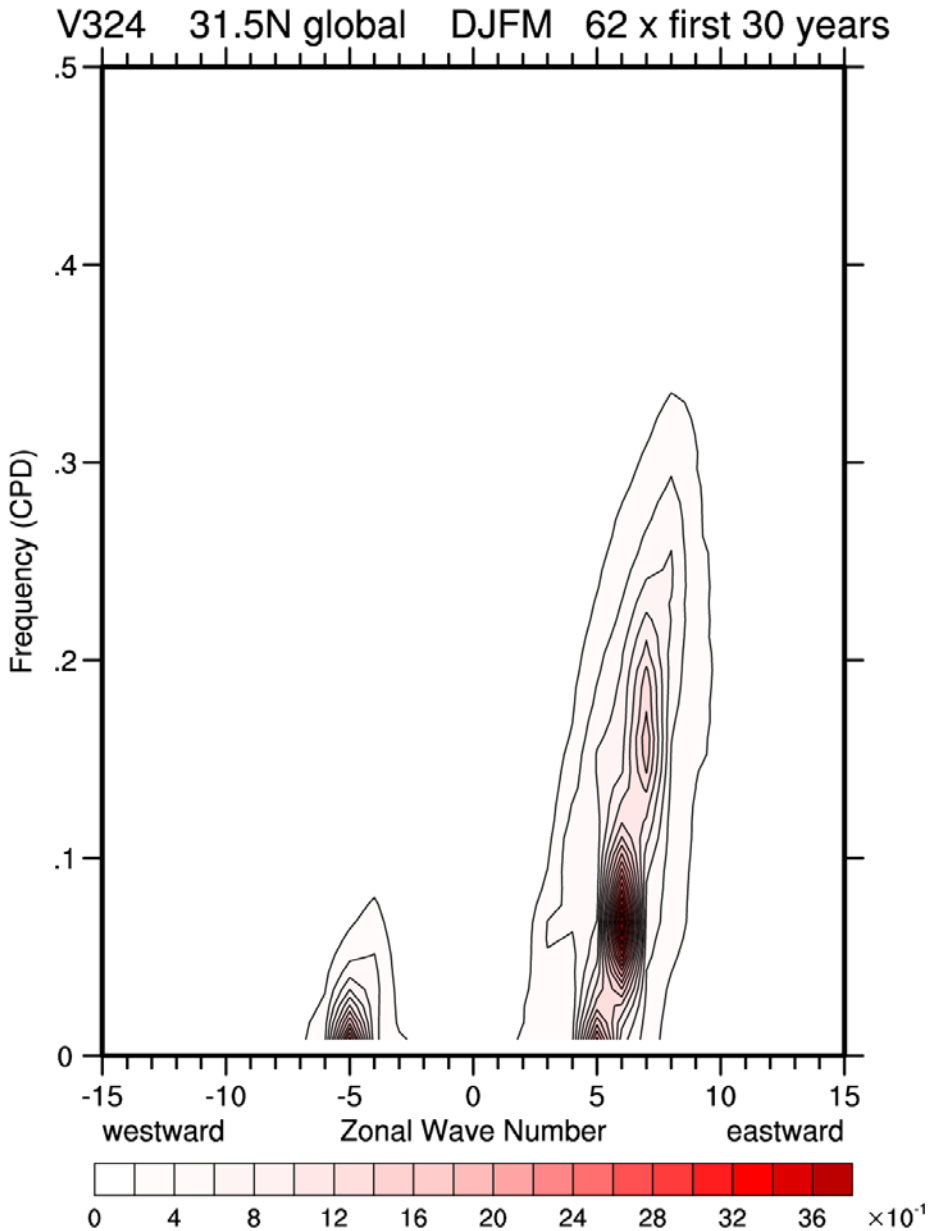

Nature



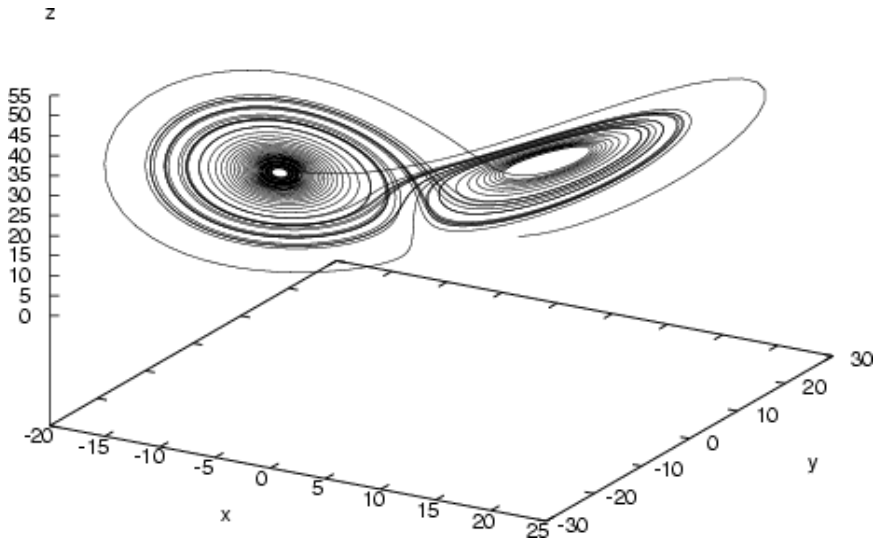
Stochastic PE




CCSM1.4

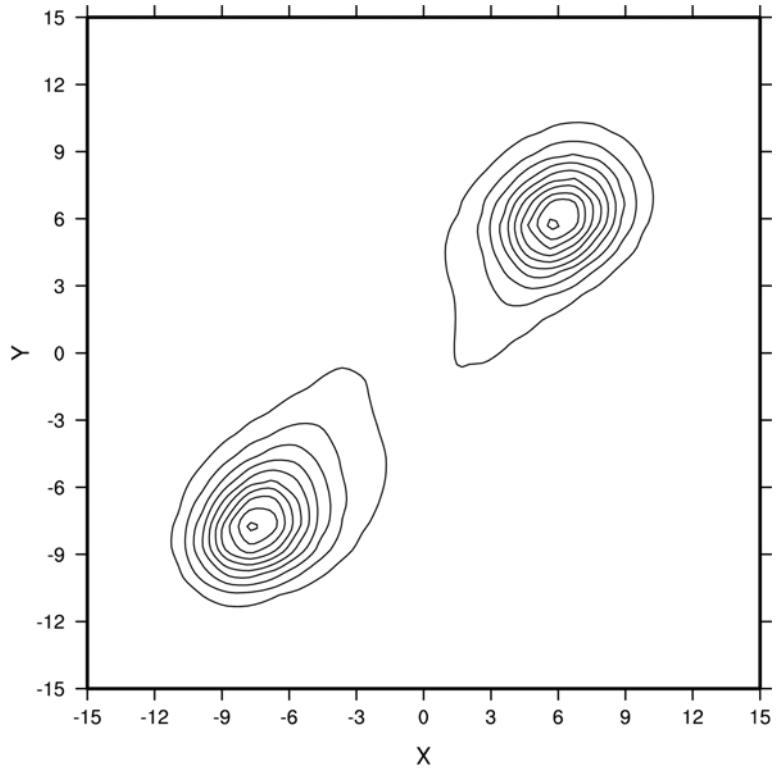


# Why does a system have natural patterns of variability? (Possibility II)

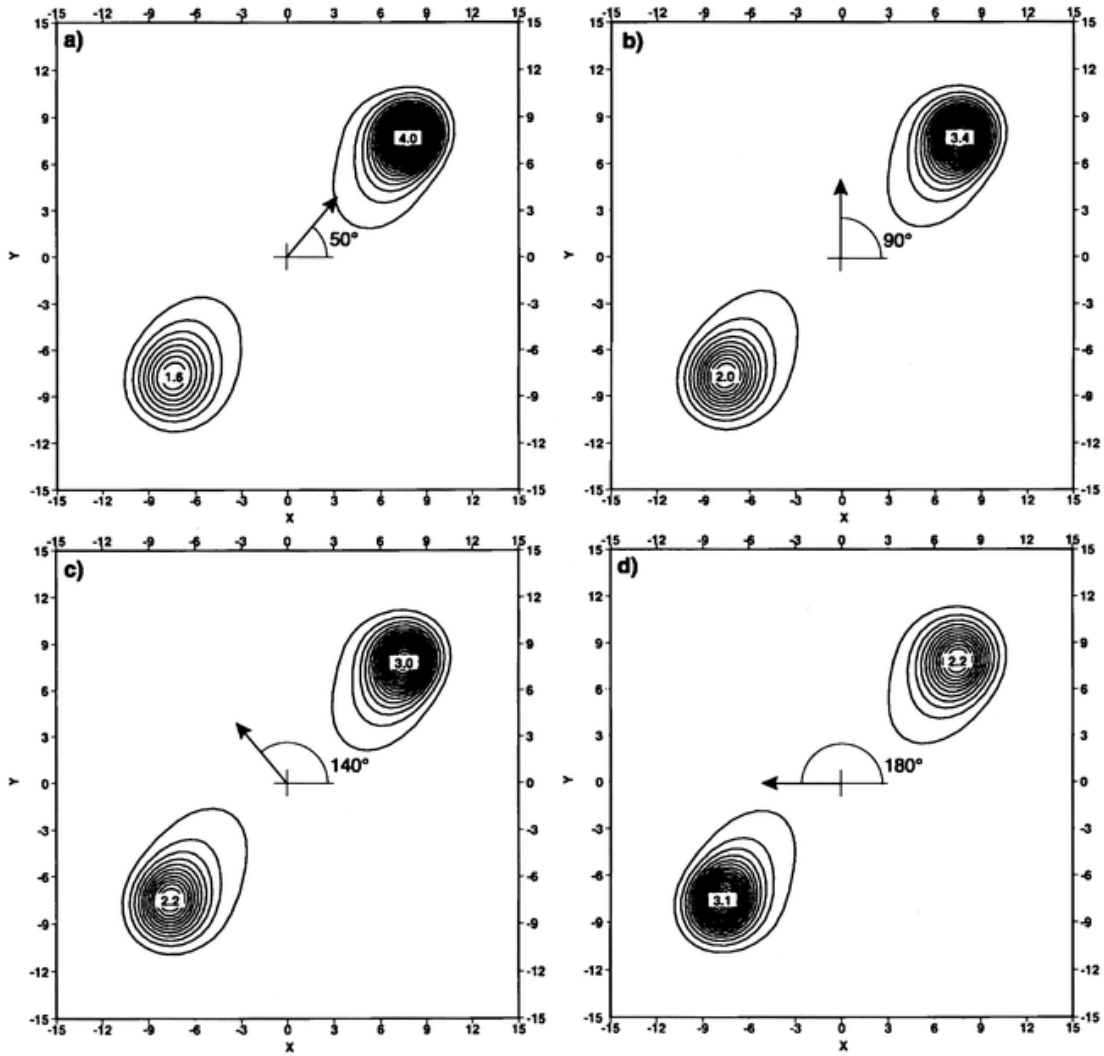



Lorenz63

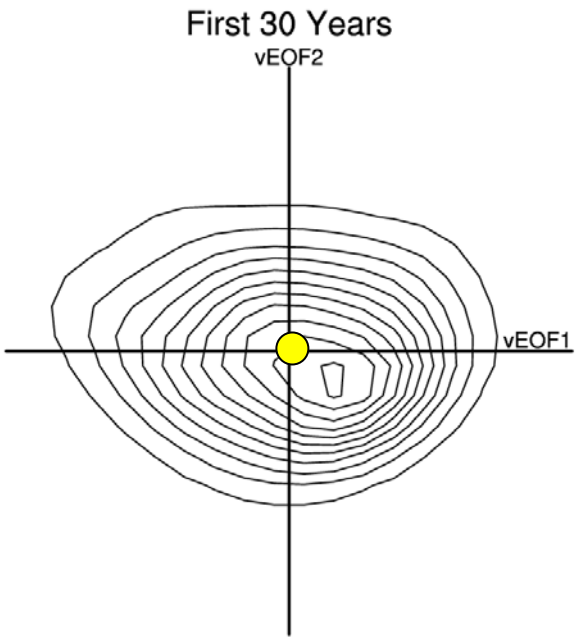
**PDF**

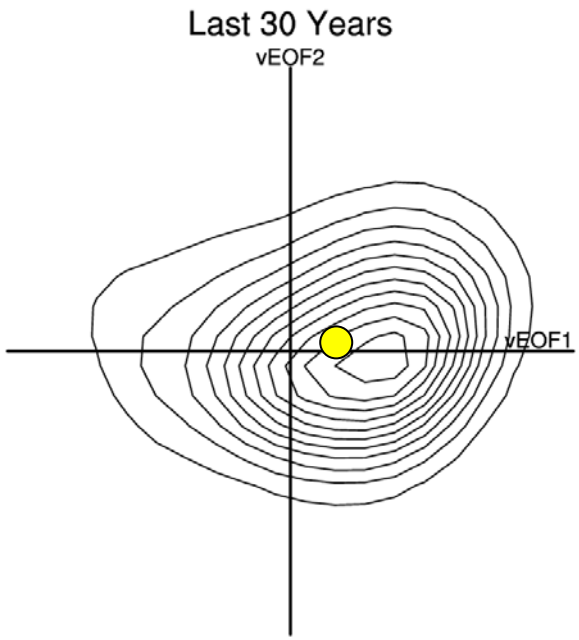


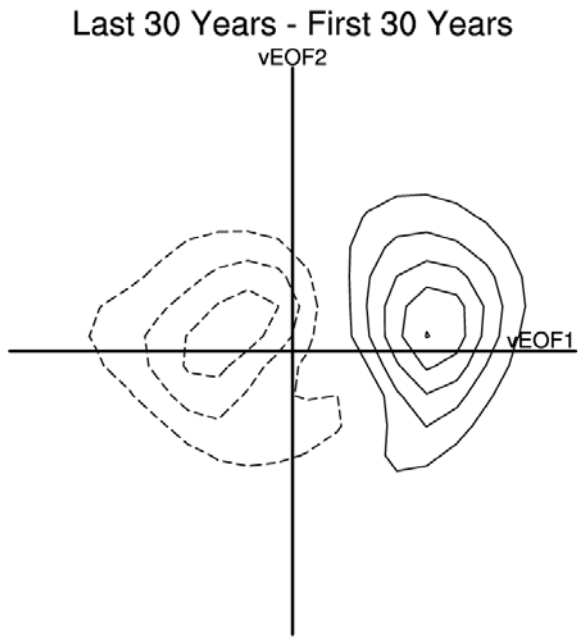
# PDFs of Forced Lorenz' 3-Parameter Model

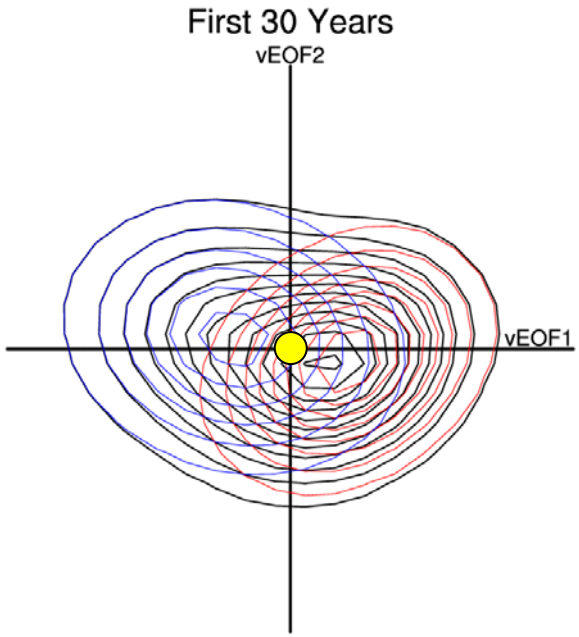


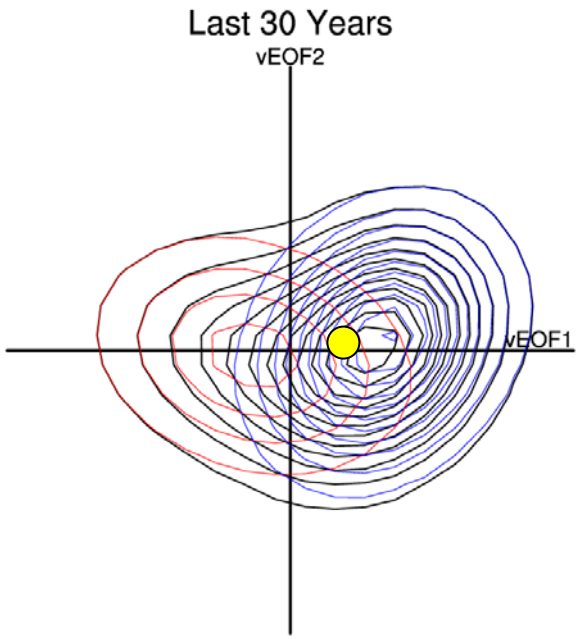

Palmer (1999)

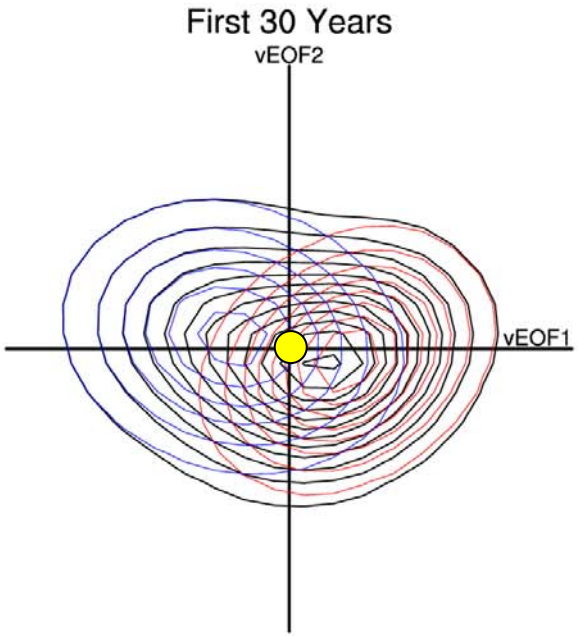

First 30 Years
vEOF2
vEOF1

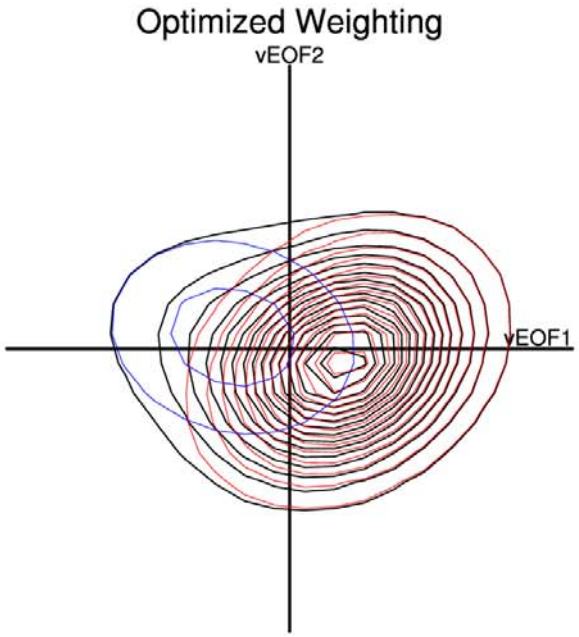

Last 30 Years
vEOF2
vEOF1

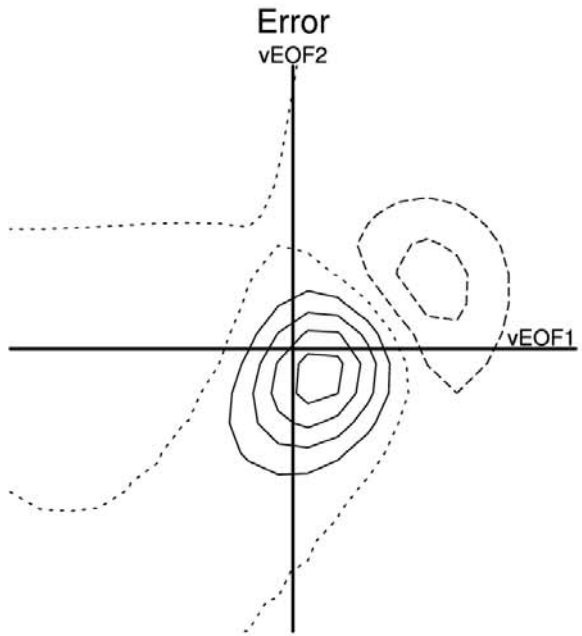

Last 30 Years - First 30 Years
vEOF2
vEOF1

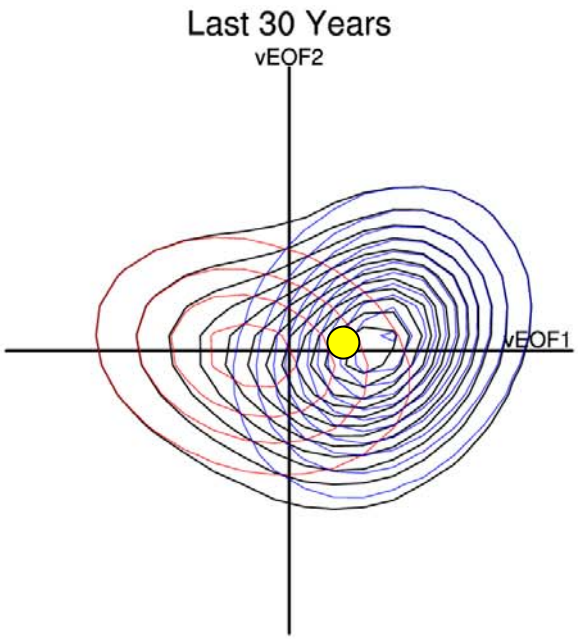

First 30 Years
vEOF2
vEOF1

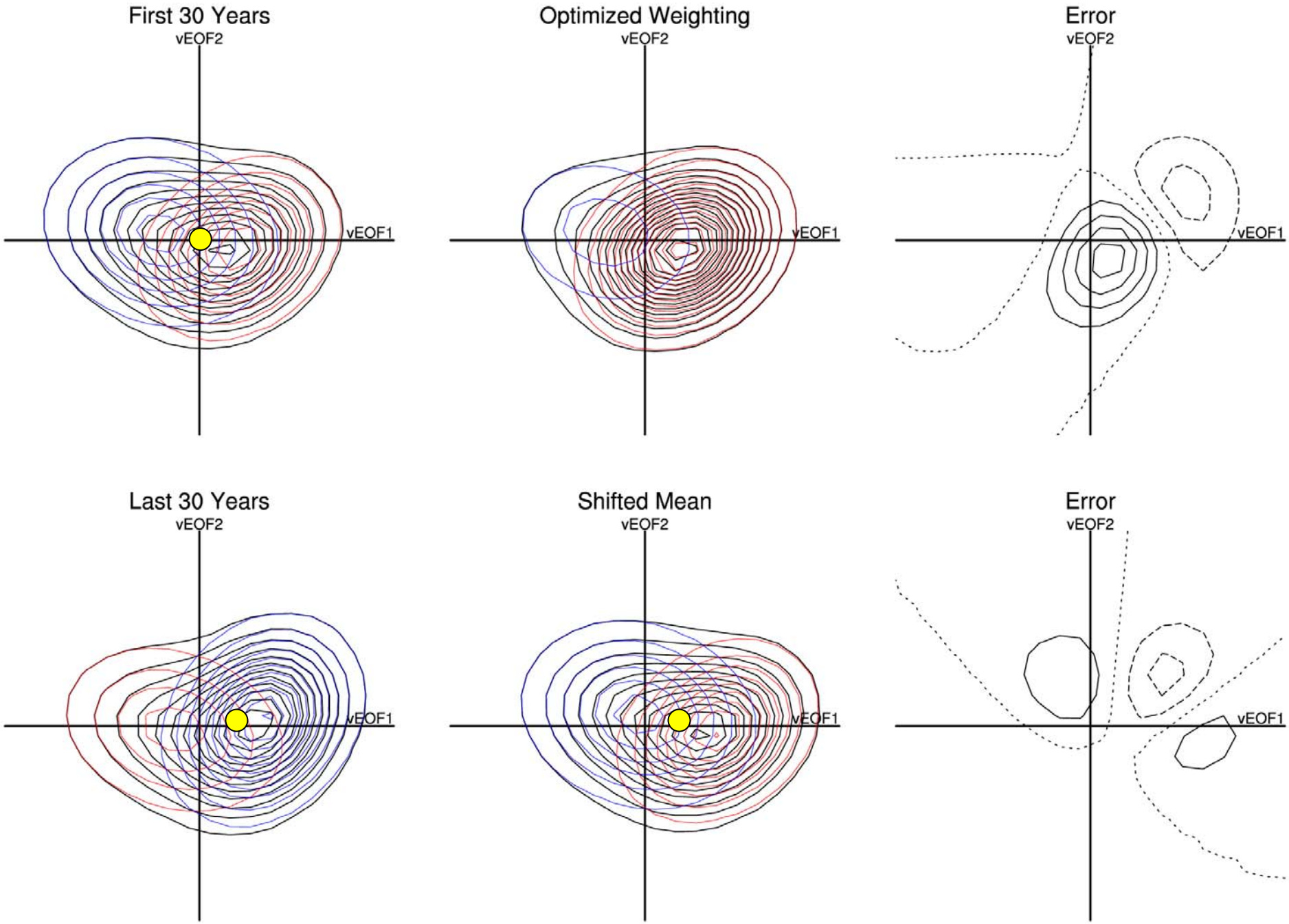

Last 30 Years
vEOF2
vEOF1

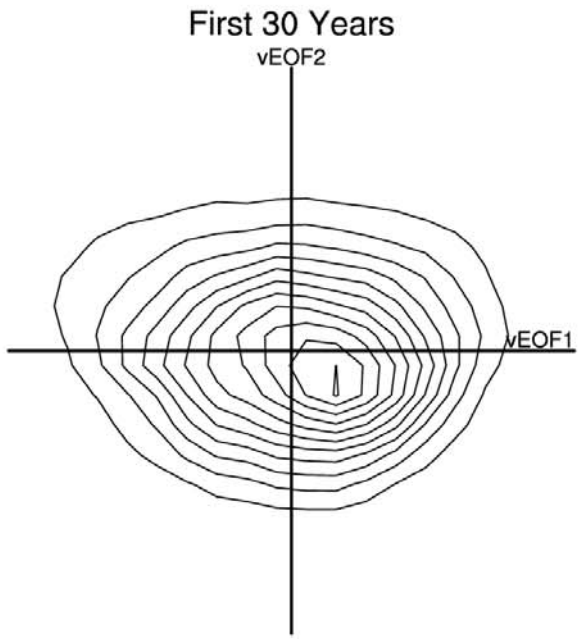

First 30 Years
vEOF2
vEOF1

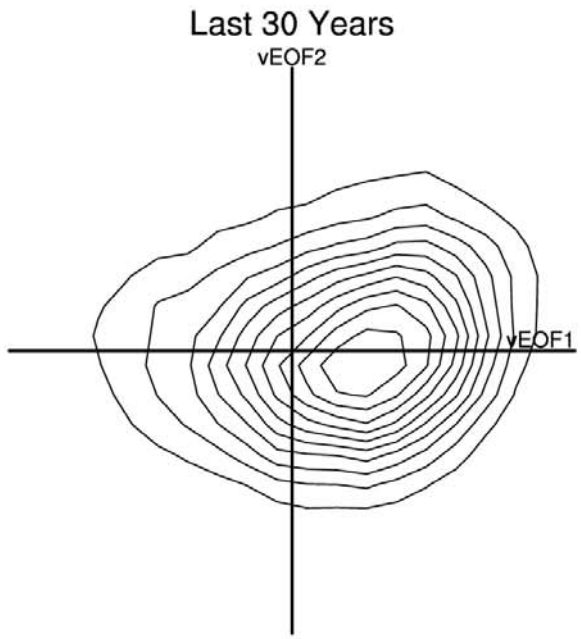

Optimized Weighting
vEOF2
vEOF1

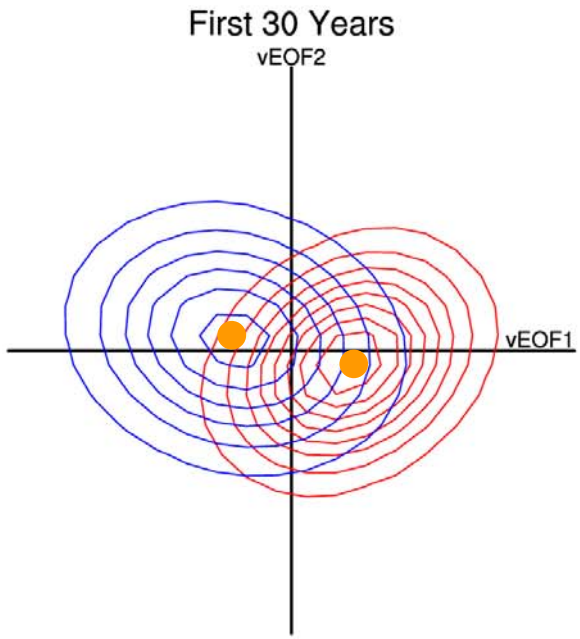

Error
vEOF2
vEOF1

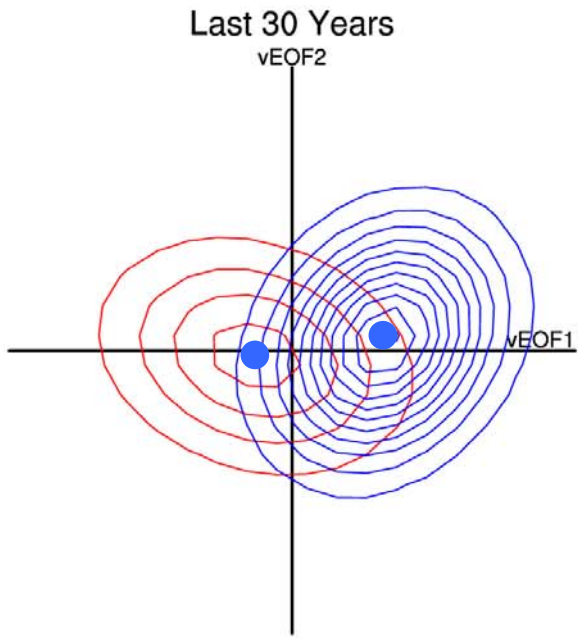

Last 30 Years
vEOF2
vEOF1

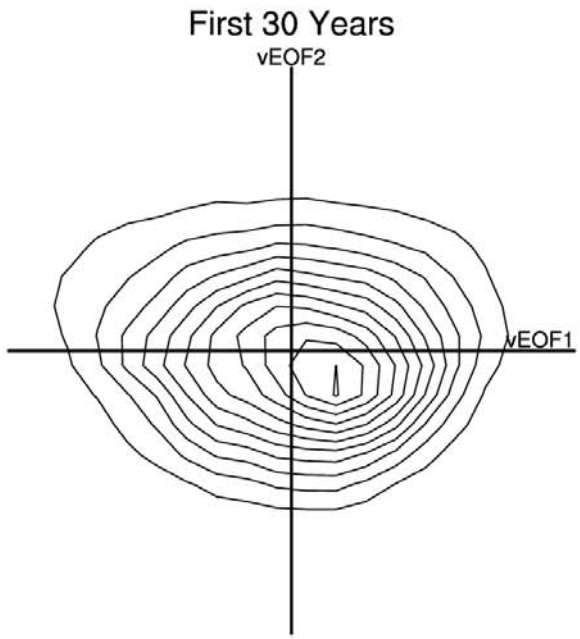

First 30 Years
vEOF2
vEOF1
Optimized Weighting
vEOF2
vEOF1
Error
vEOF2
vEOF1
Last 30 Years
vEOF2
vEOF1
Shifted Mean
vEOF2
vEOF1
Error
vEOF2
vEOF1

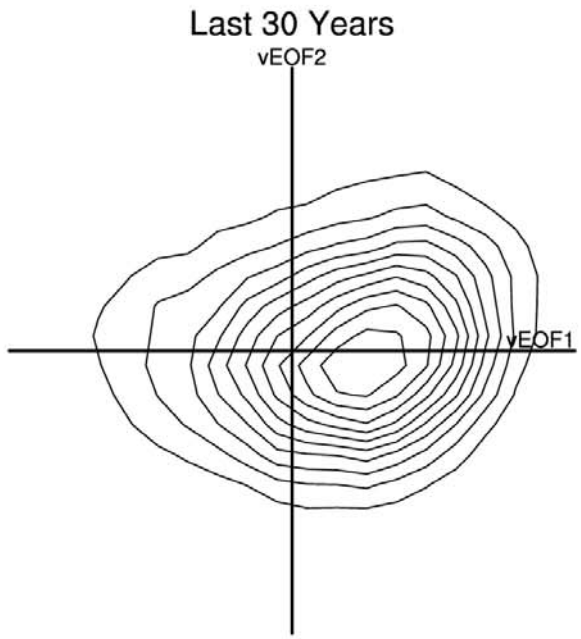

First 30 Years
vEOF2
vEOF1

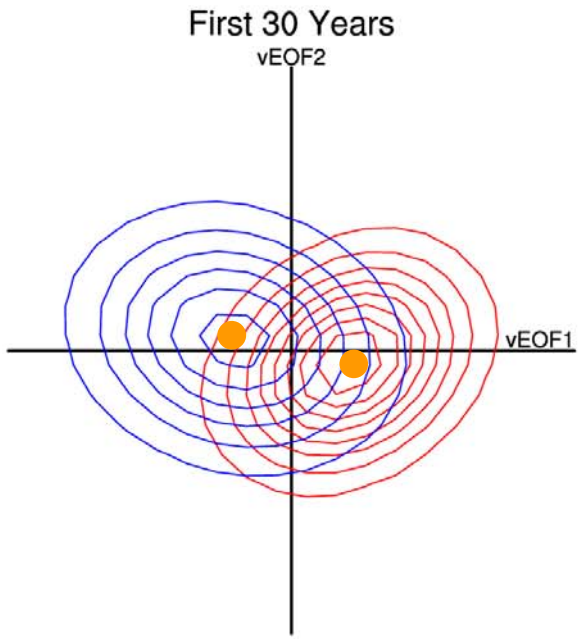

Last 30 Years
vEOF2
vEOF1

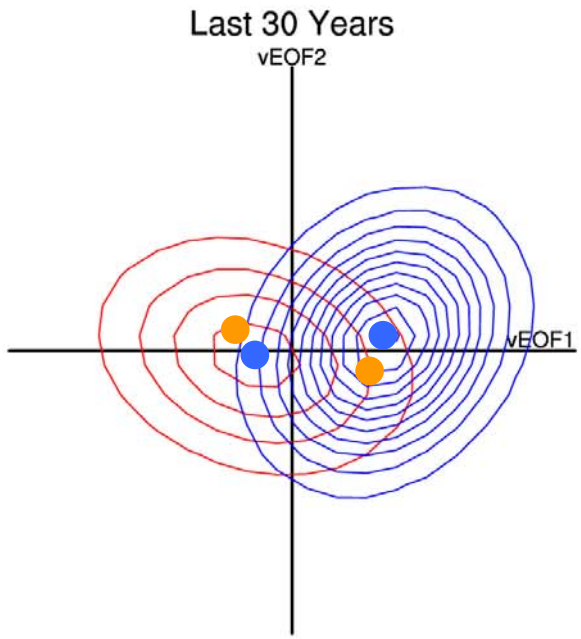

First 30 Years
vEOF2
vEOF1

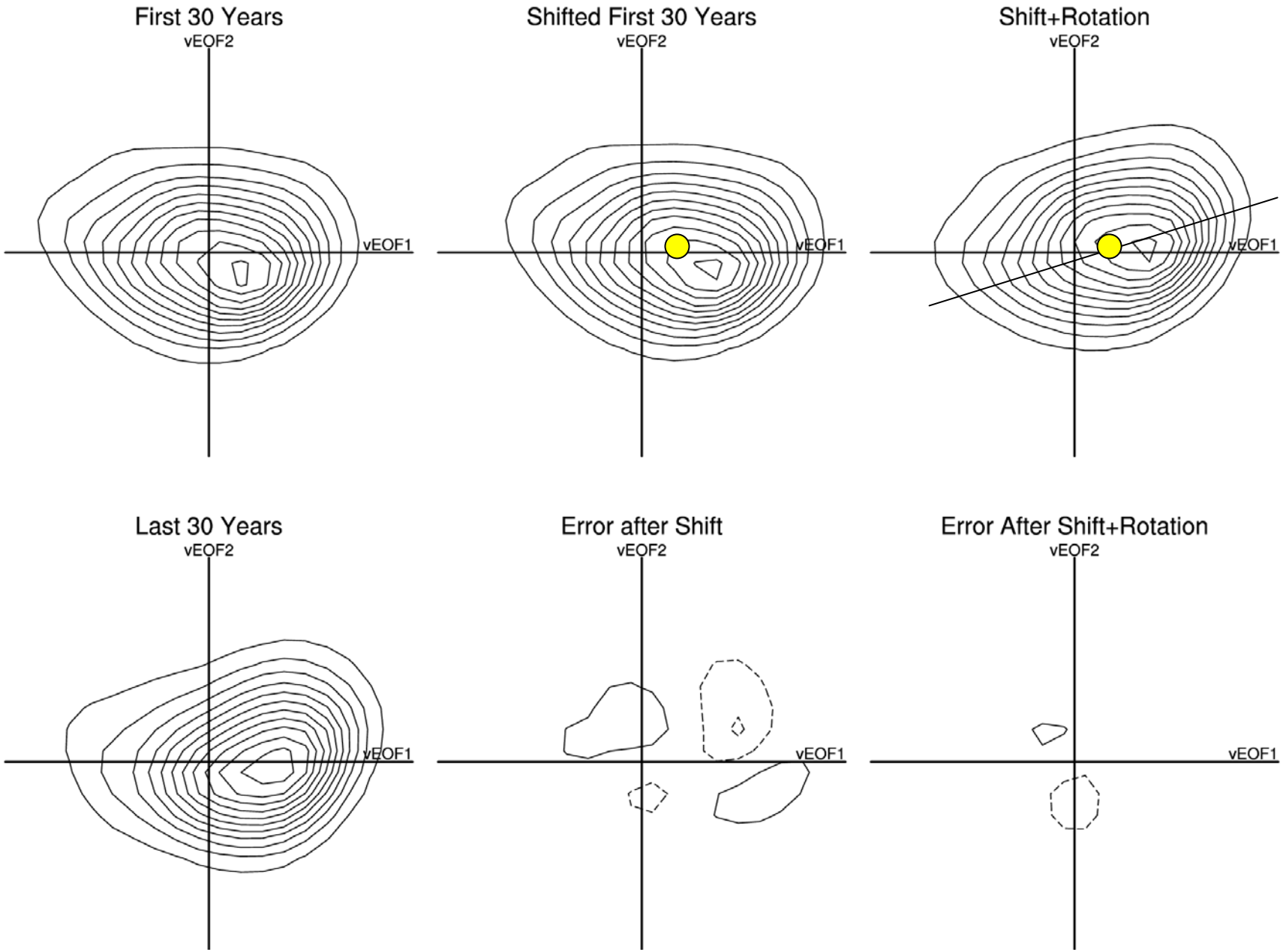

Last 30 Years
vEOF2
vEOF1


First 30 Years
vEOF2
vEOF1

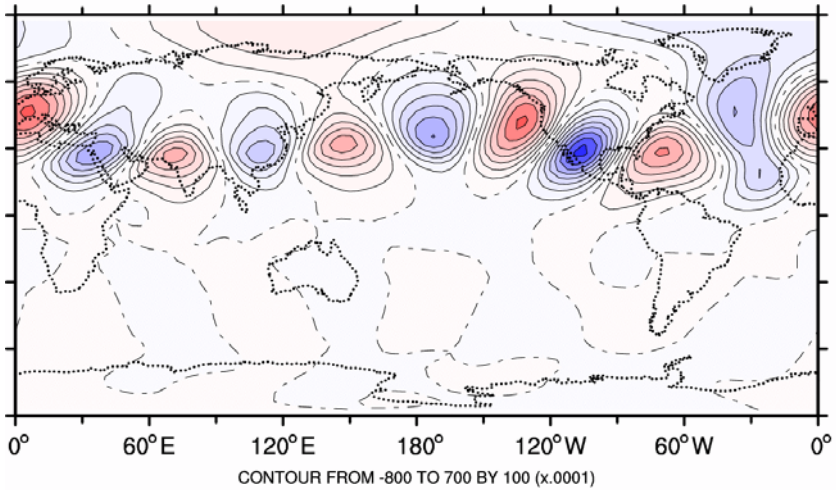

Last 30 Years
vEOF2
vEOF1


First 30 Years
vEOF2
vEOF1


Last 30 Years
vEOF2
vEOF1

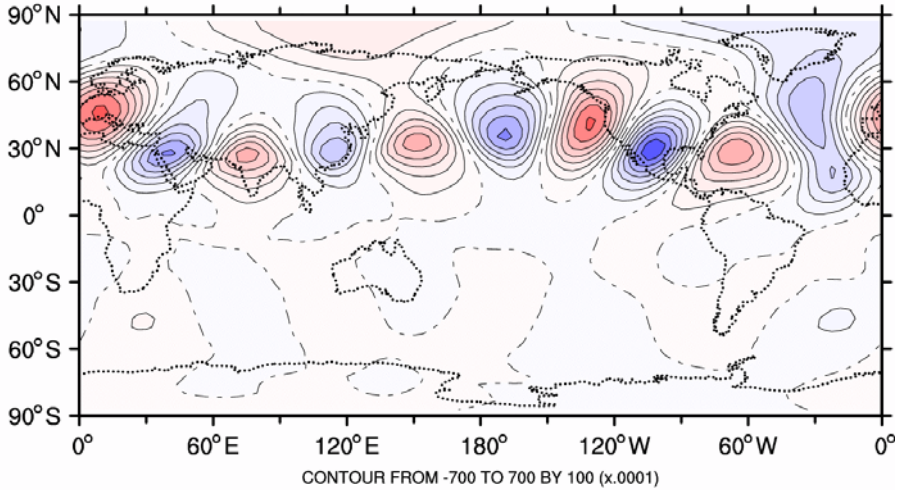

First 30 Years
vEOF2
vEOF1
Shifted First 30 Years
vEOF2
vEOF1
Shift+Rotation
vEOF2
vEOF1
Last 30 Years
vEOF2
vEOF1
Error after Shift
vEOF2
vEOF1
Error After Shift+Rotation
vEOF2
vEOF1

EOF 1
first 30 yrs
KNMI.62.v300 Jan



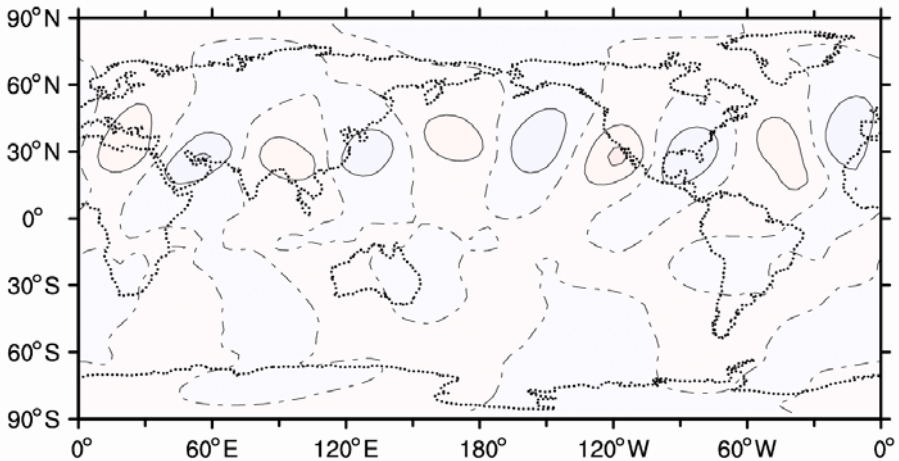

CONTOUR FROM -800 TO 700 BY 100 (x.0001)

EOF 1
last 30 yrs
KNMI.62.v300 Jan



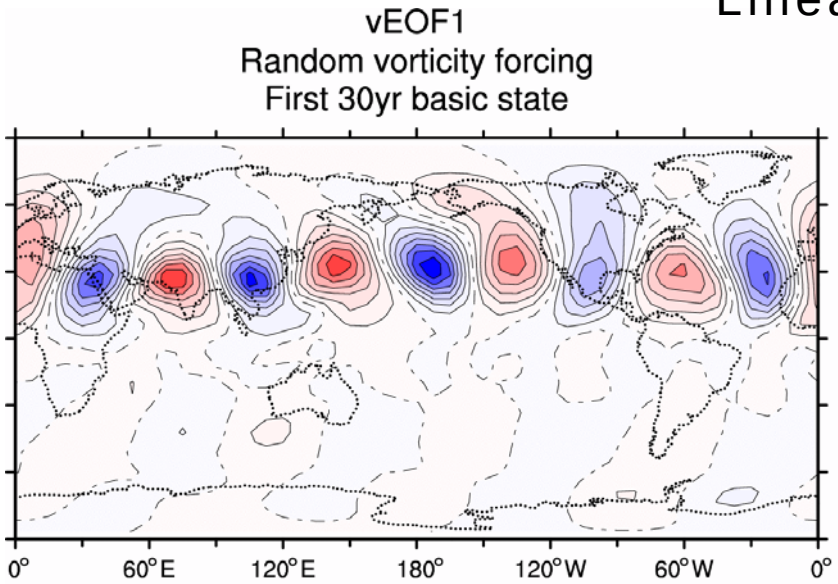

CONTOUR FROM -700 TO 700 BY 100 (x.0001)

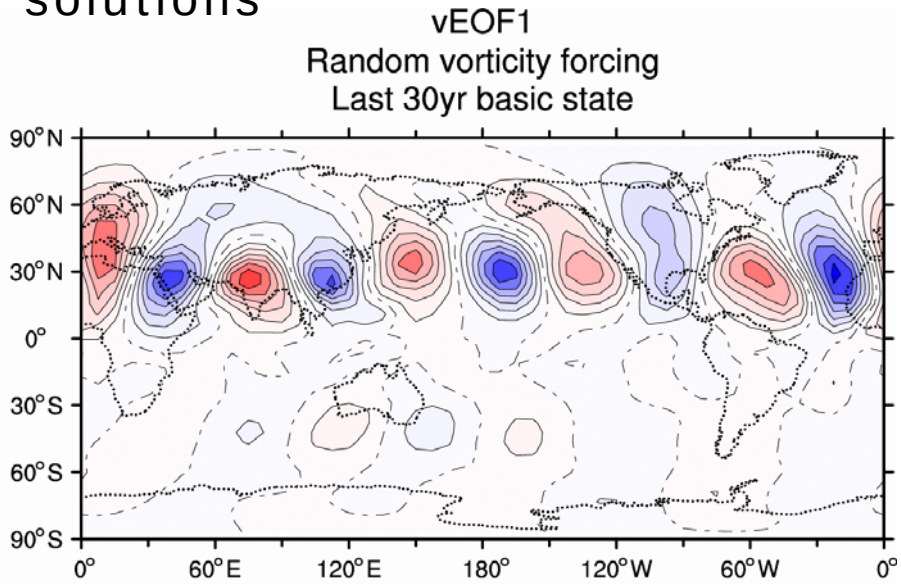
EOF 1
last 30yrs - first 30yrs
KNMI.62.v300 Jan

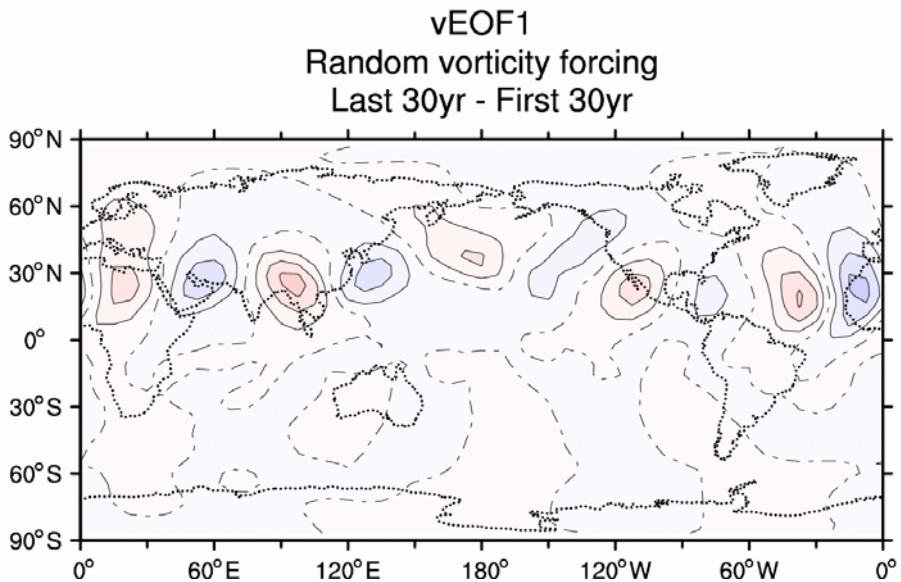



CONTOUR FROM -200 TO 200 BY 100 (x.0001)

# Linear solutions

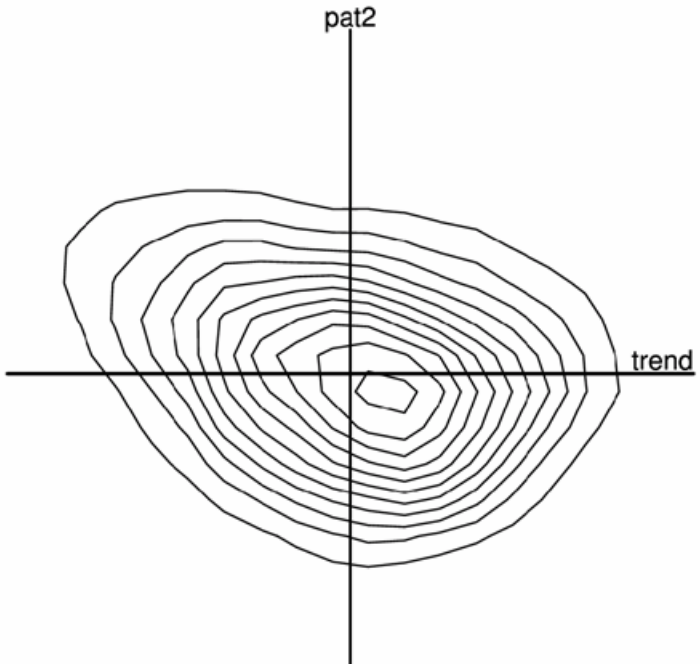


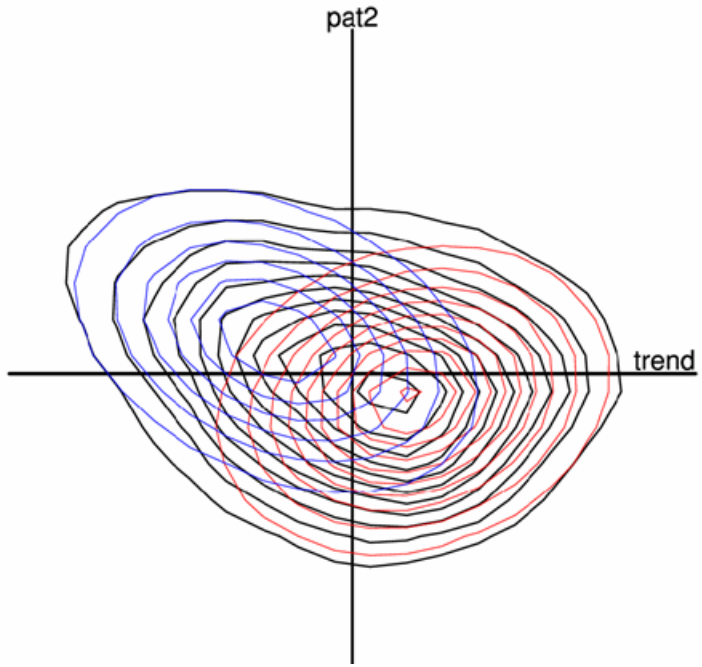



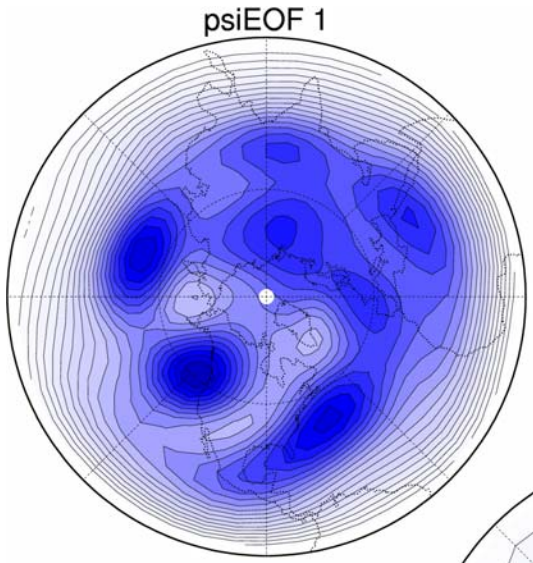
# Part II

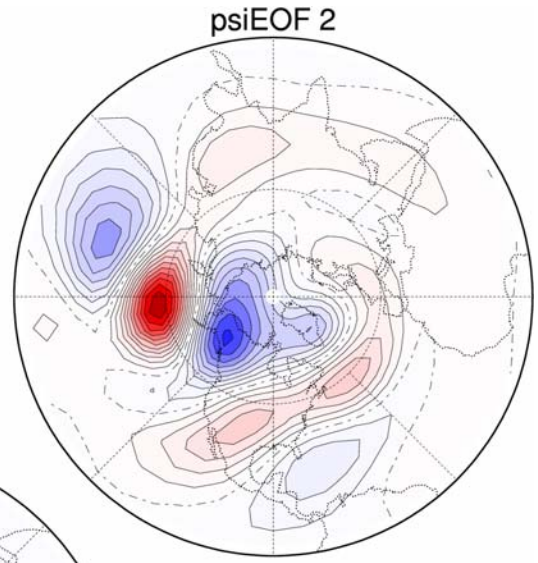
## Stochastic parameterization of unresolved scales

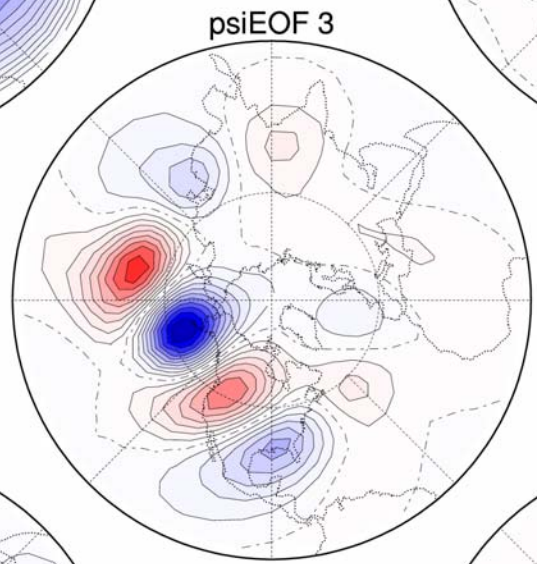


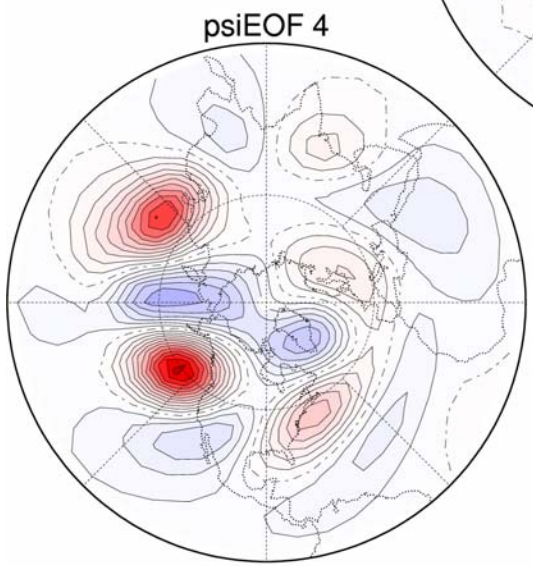



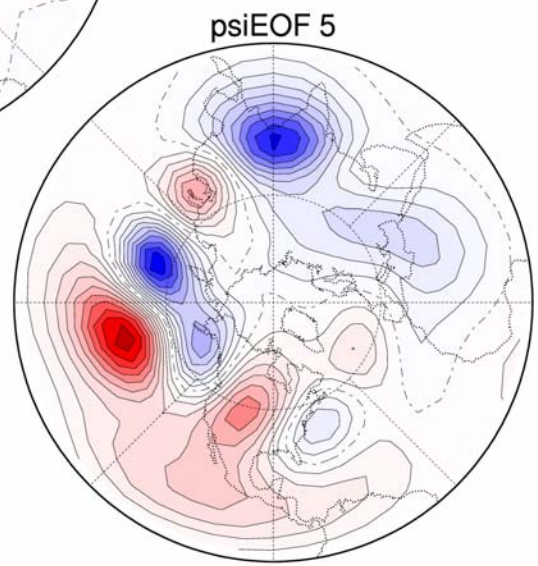
# CCM0
# psi300


psiEOF 1
CONTOUR FROM -800 TO 0 BY 40 (x.001)

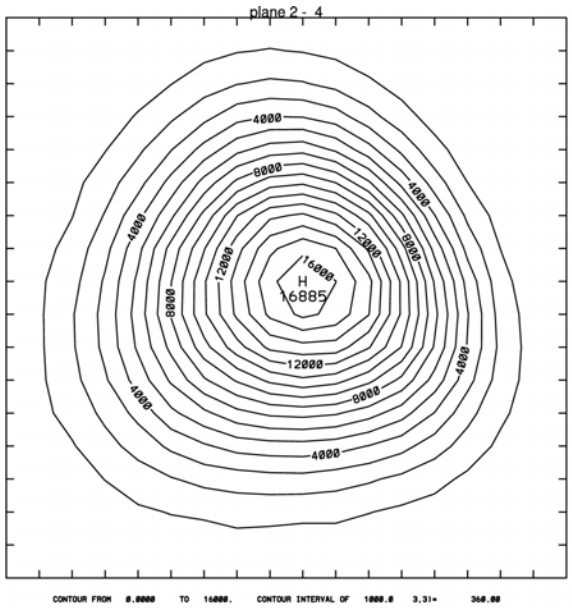

psiEOF 2
CONTOUR FROM -225 TO 275 BY 25 (x.01)

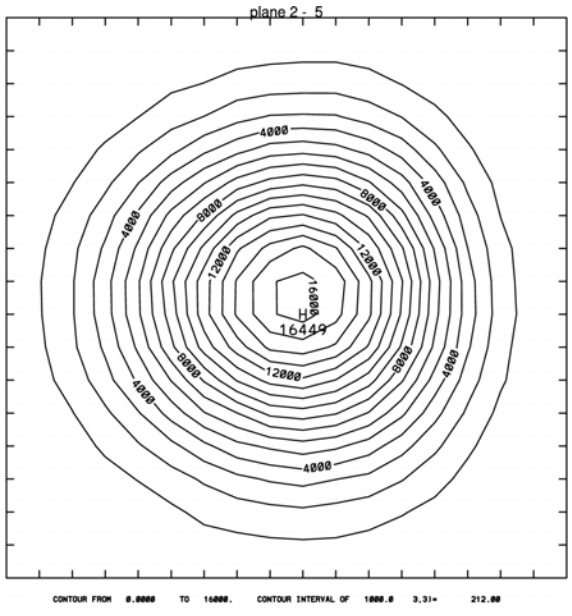

psiEOF 3
CONTOUR FROM -300 TO 240 BY 30 (x.01)


psiEOF 4
CONTOUR FROM -150 TO 300 BY 25 (x.01)

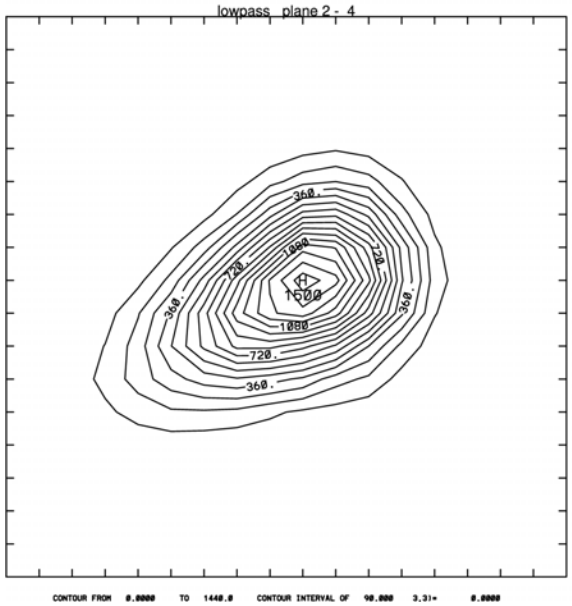

psiEOF 5
CONTOUR FROM -180 TO 200 BY 20 (x.01)

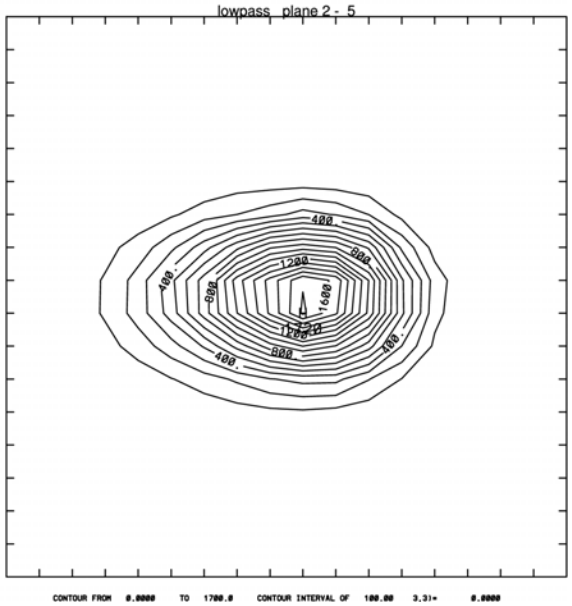
# 2-4 CCM0 PDFs 2-5



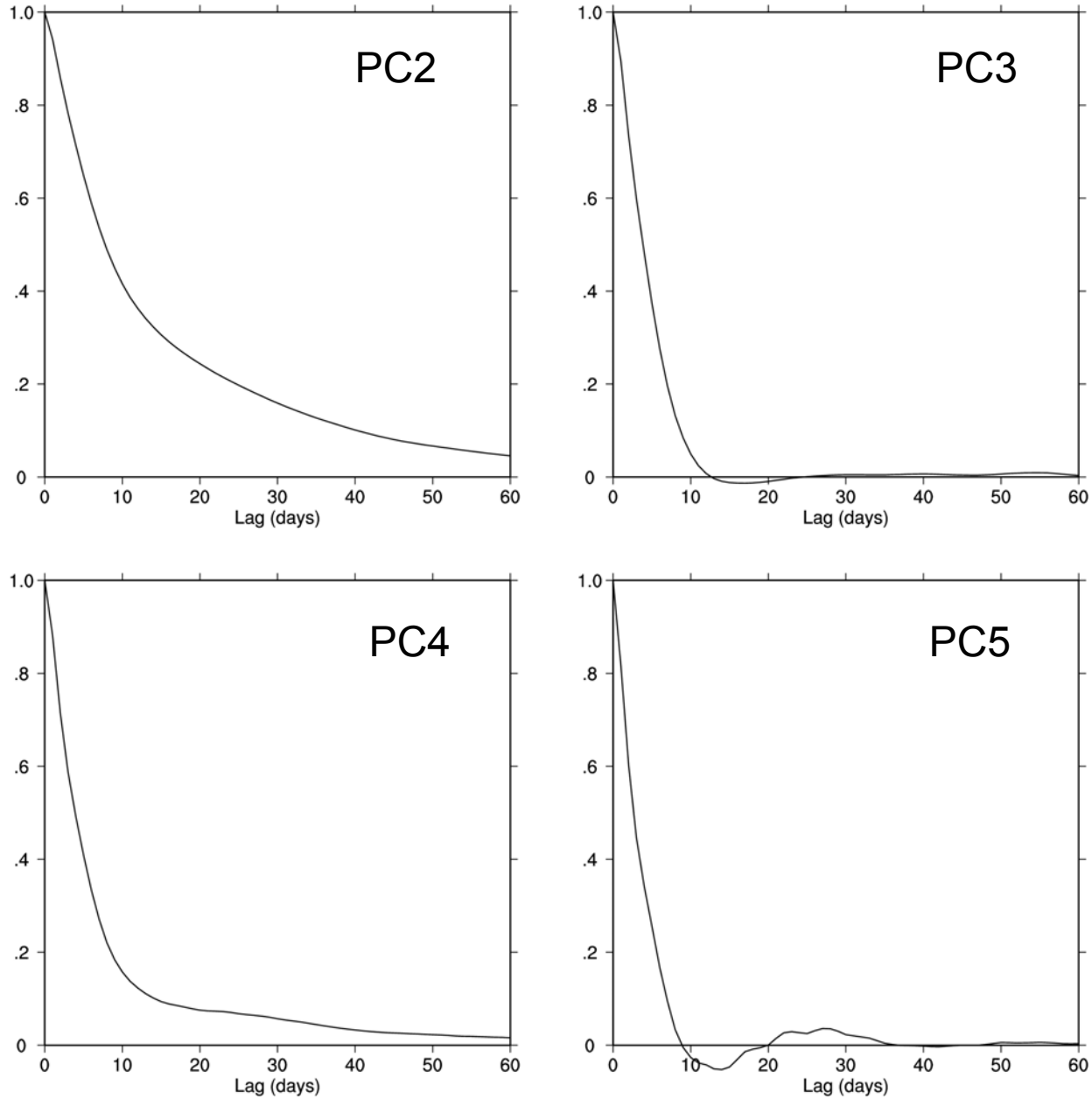

Instantaneous



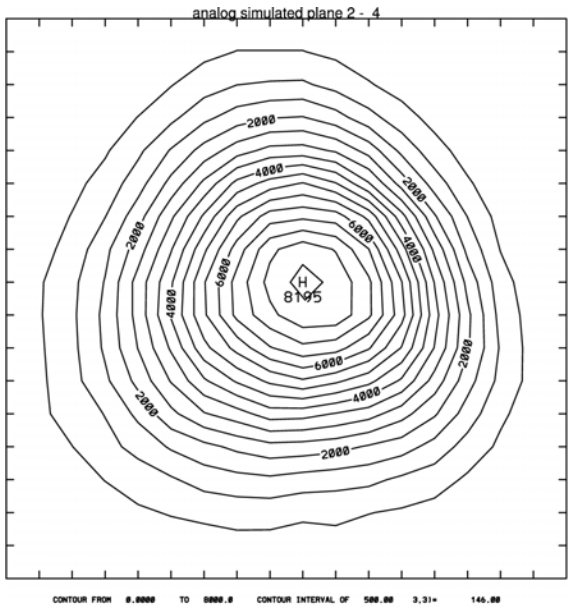

30d means

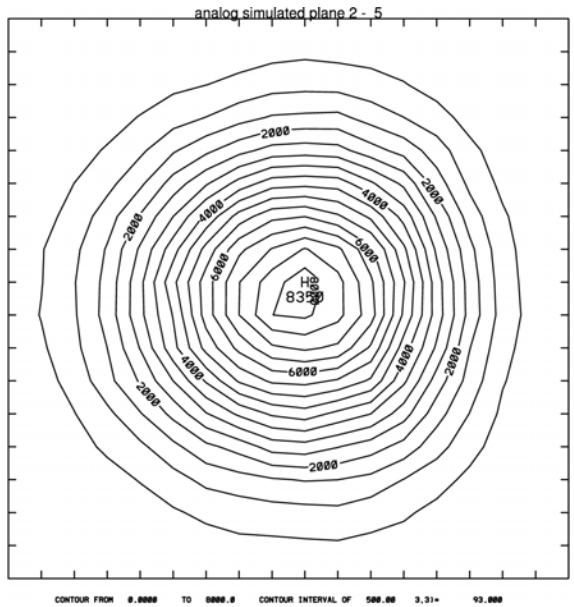
# CCM0 lag correlations



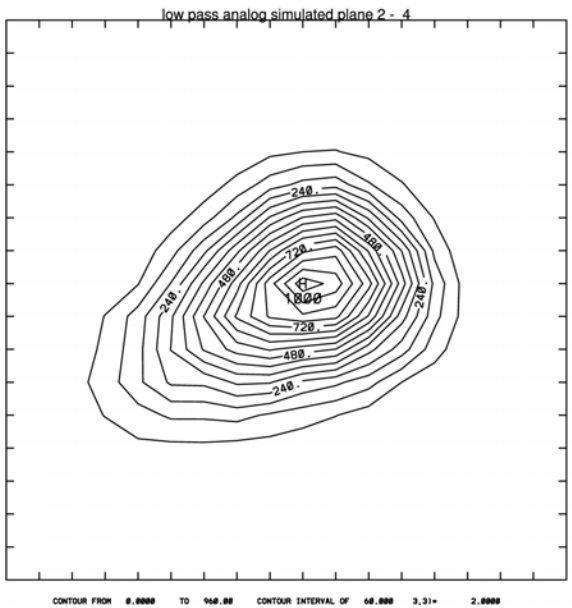
# PDFs

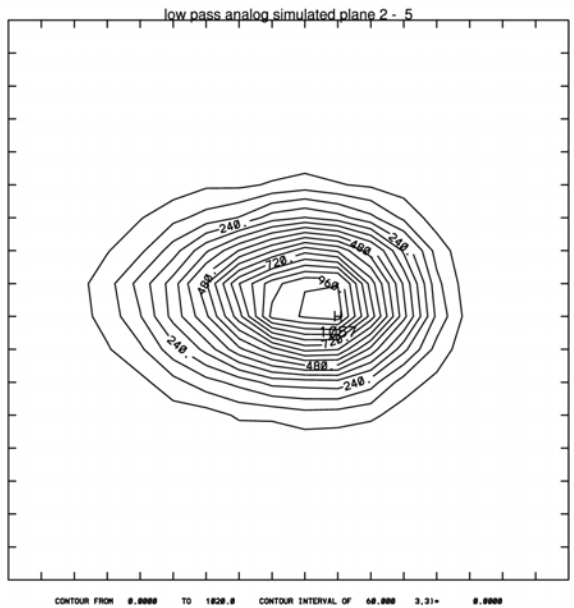
## 2-4 Analog Δt=36h march 2-5



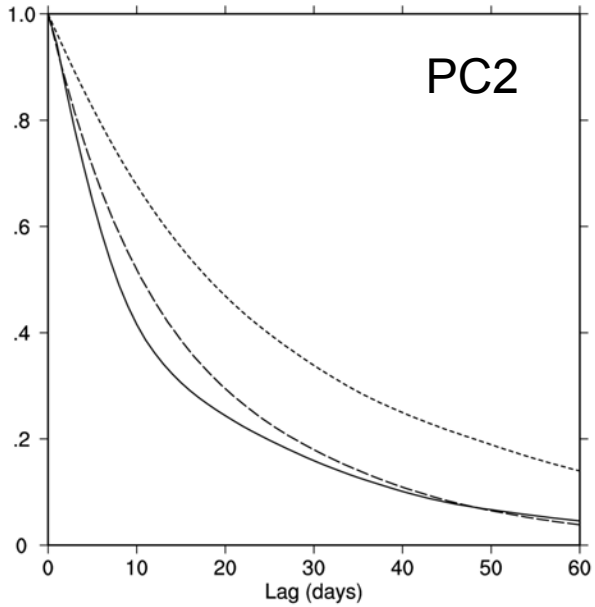

Instantaneous

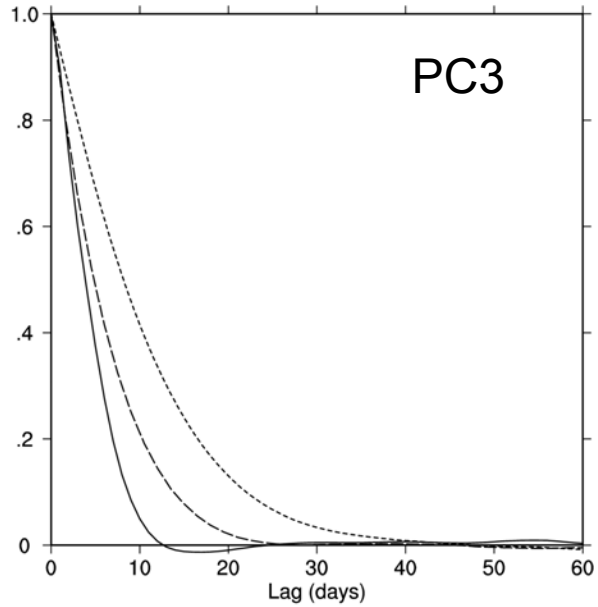


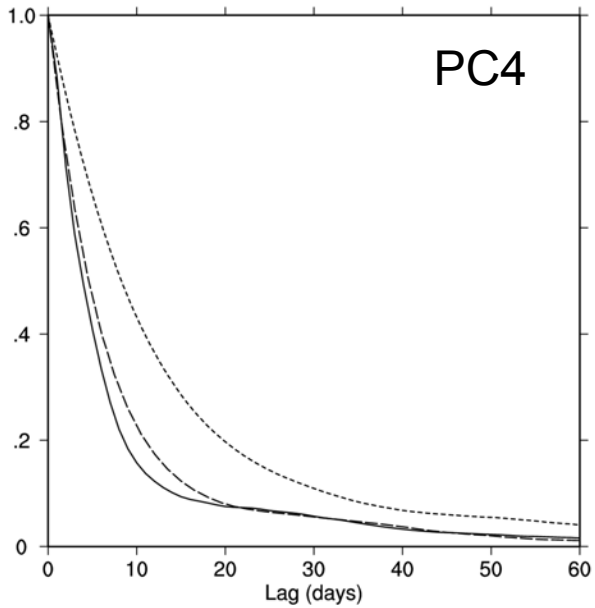



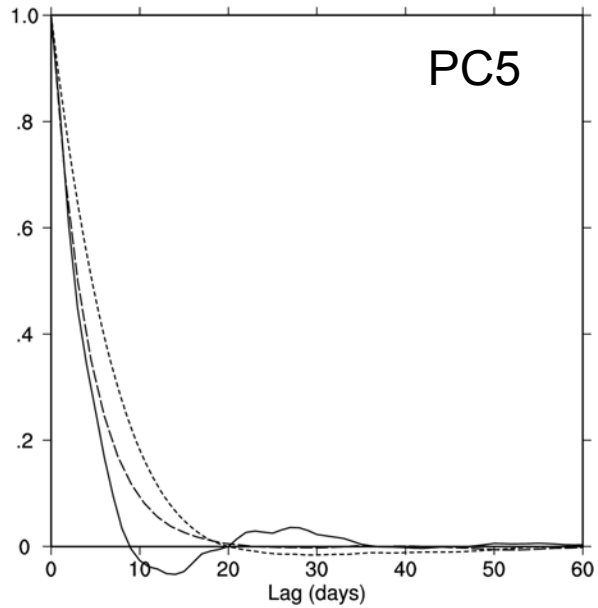

30d means

# Analog march lag correlations



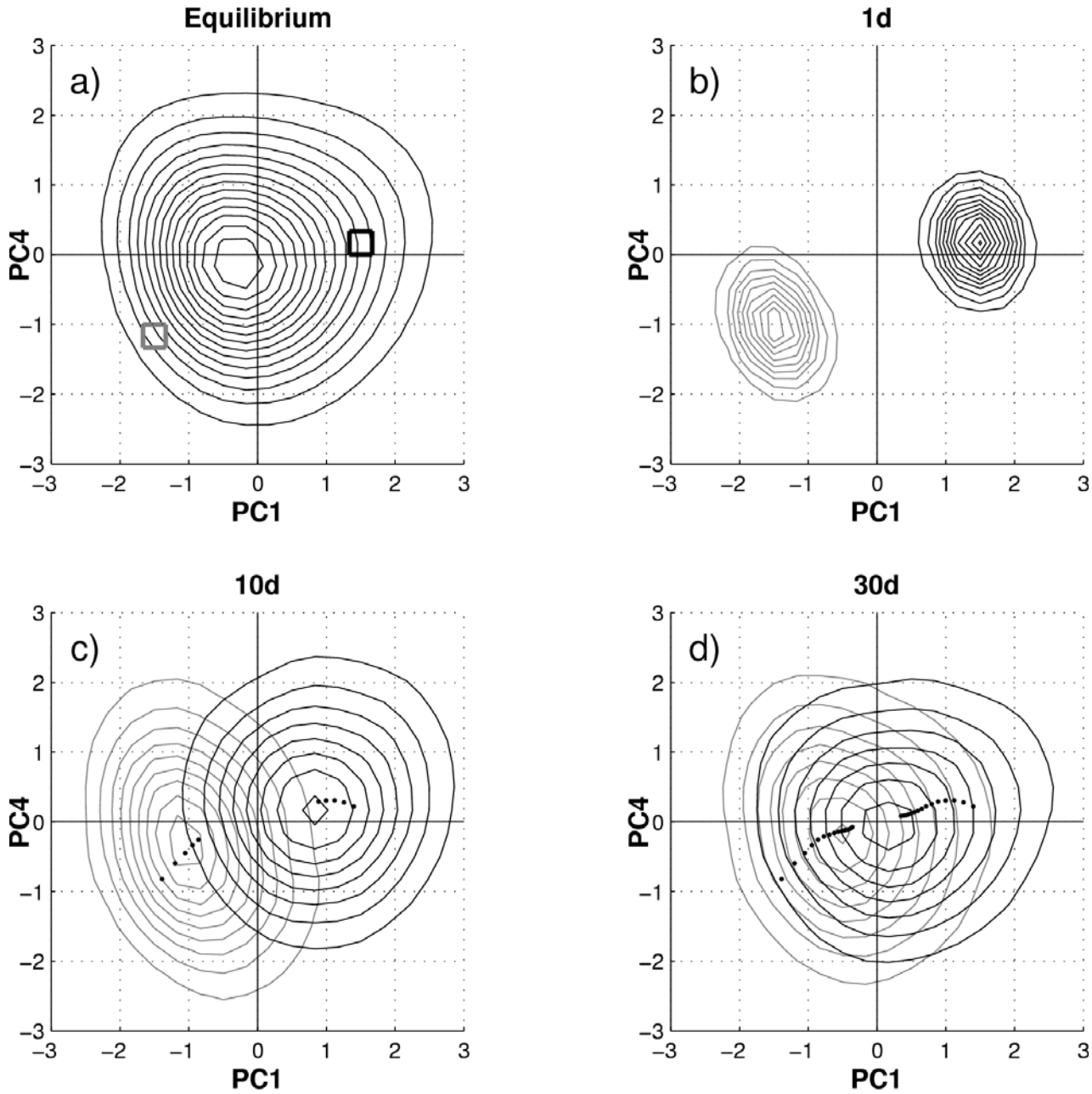




CCM0

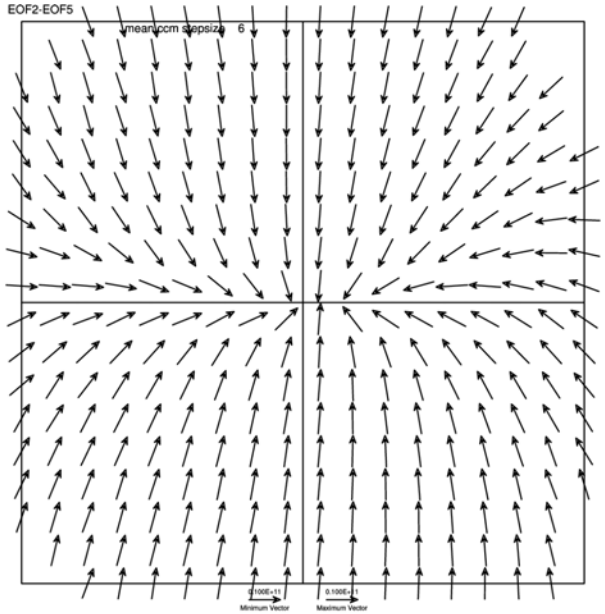
36hr analog

12h analog

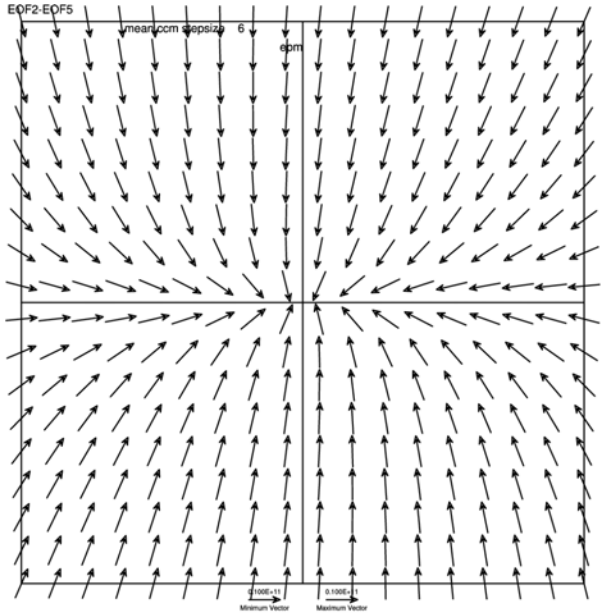



Branstator & Berner (2005)

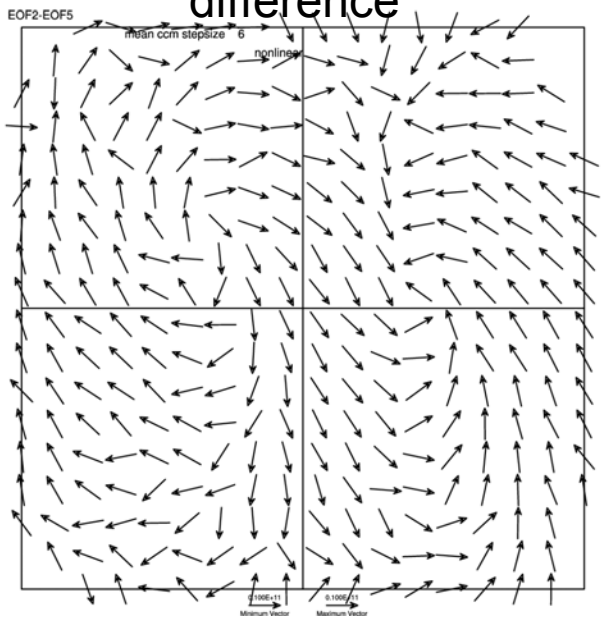
36h mean tendency directions




LIM fit




difference




2-5 plane

LIM:

$$s_{t+\tau} = C_\tau C_0^{-1} s_t$$

$$s_{t+\tau}^{(5)} = LIM^{(5)} s_t^{(5)} + noise$$

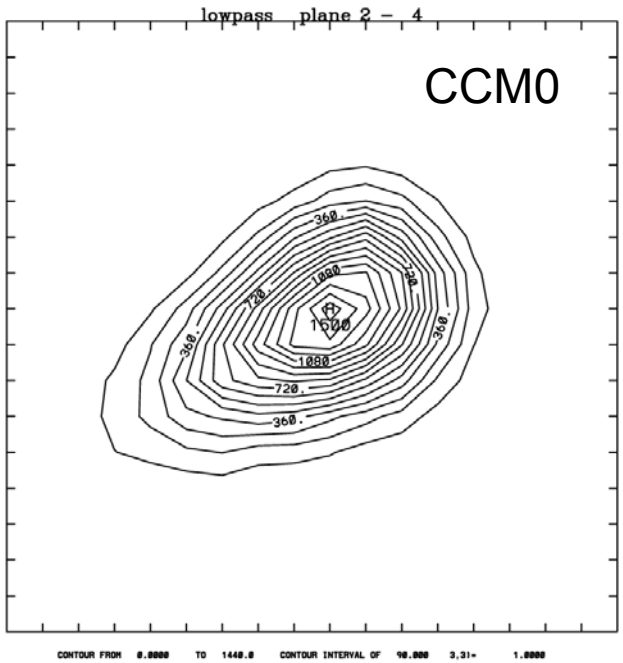
$$s_{t+\tau}^{(495)} = LIM^{(495)} s_t^{(495)} + noise$$

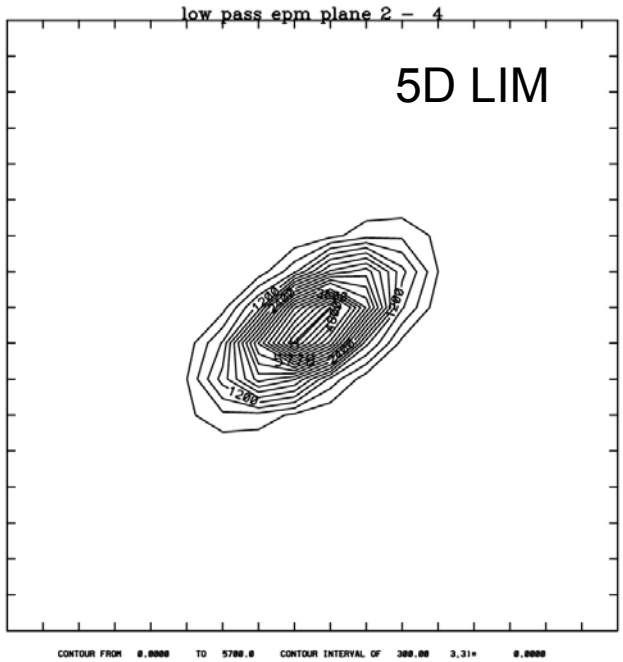
$$s_{t+\tau}^{(5)} = (NN_{nonlinear}^{(5)} + LIM^{(5)}) s_t^{(5)} + noise$$

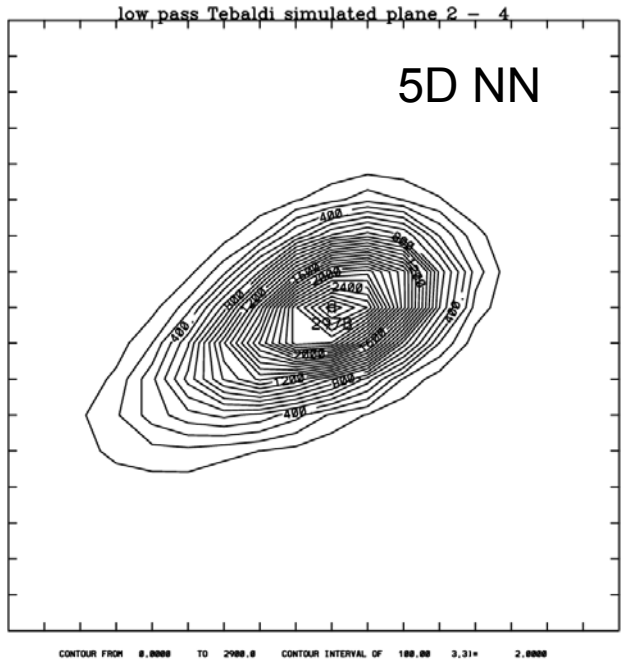
$$= NN^{(5)} s_t^{(5)} + noise$$

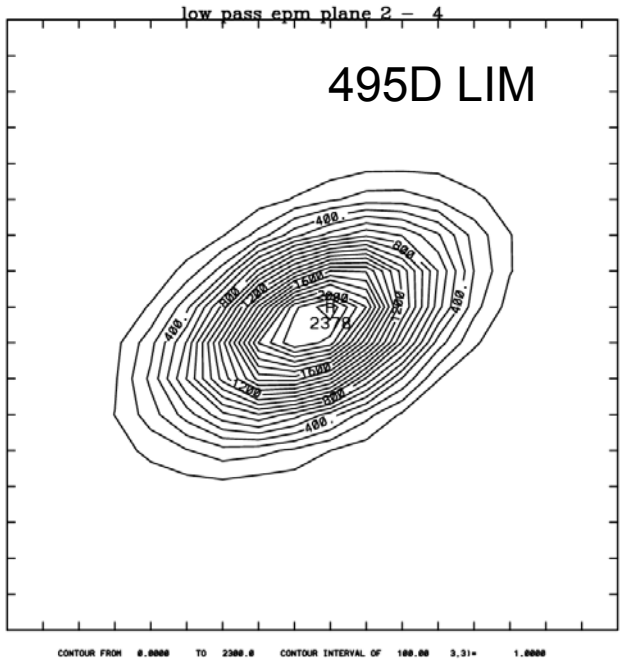
$$s_{t+\tau}^{(495)} = (NN_{nonlinear}^{(5)} + LIM^{(495)}) s_t^{(495)} + noise$$

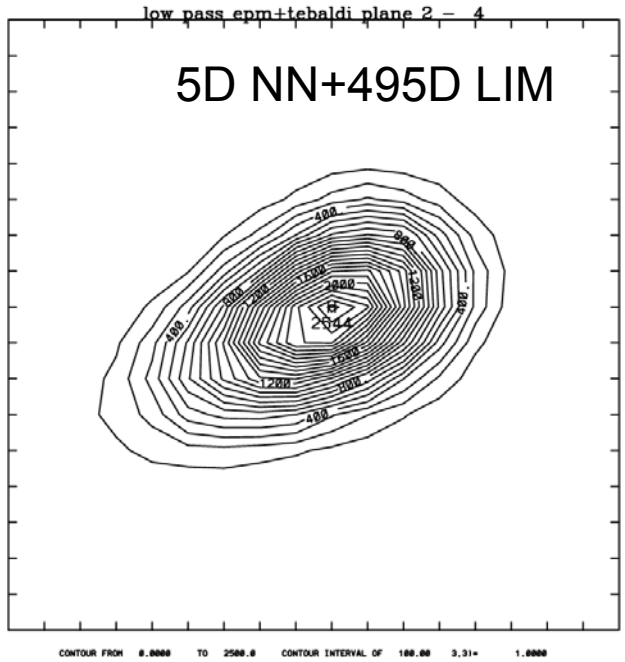
PDFs of 30d means
in plane 2-4



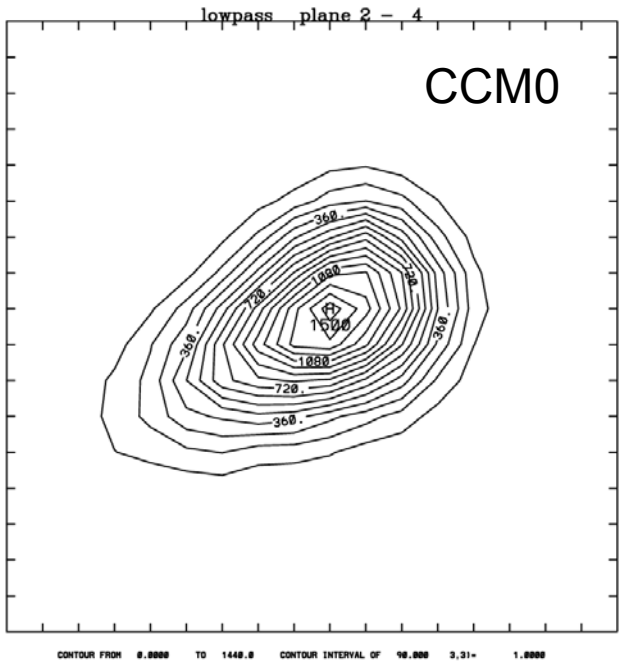



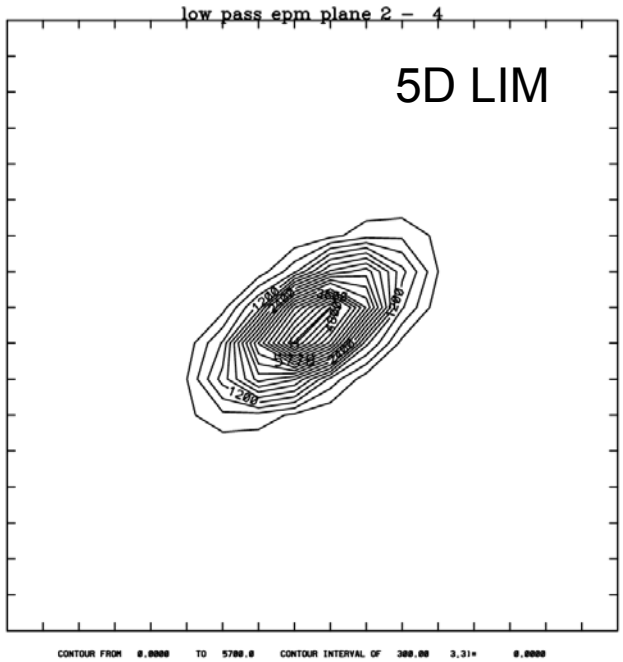



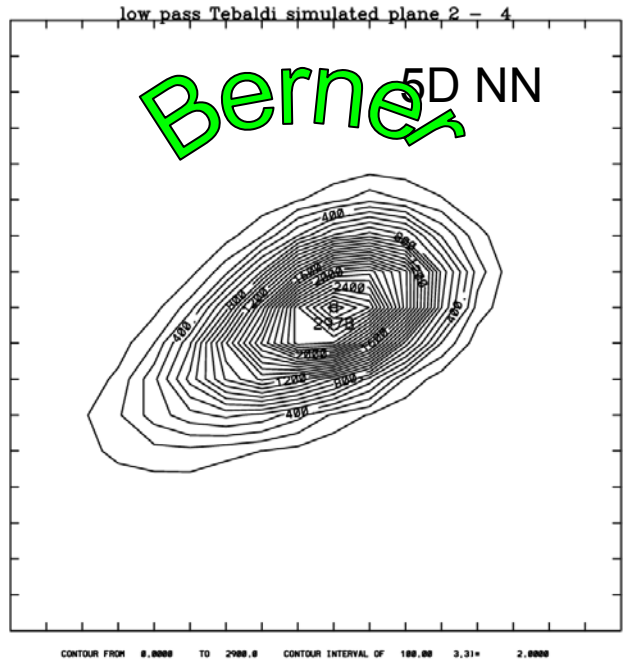



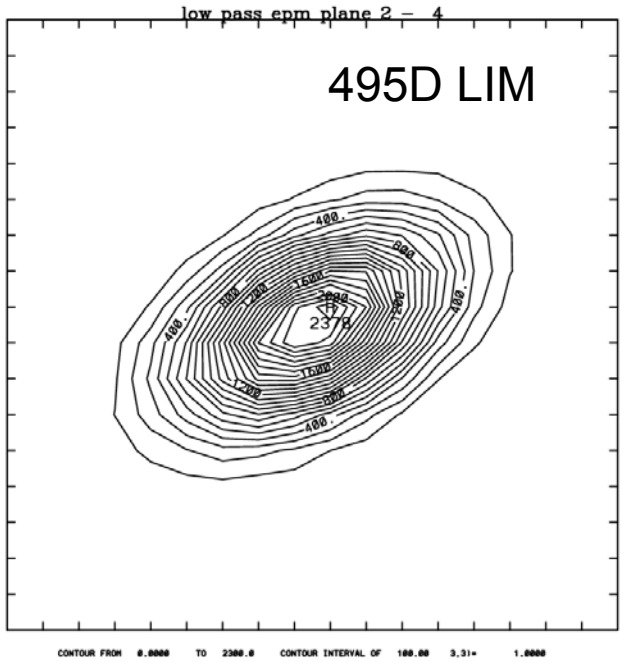



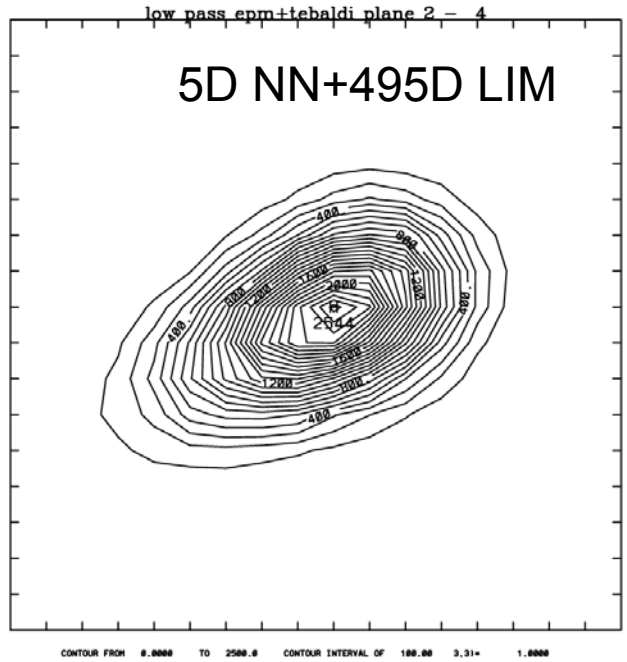
PDFs of 30d means
in plane 2-4



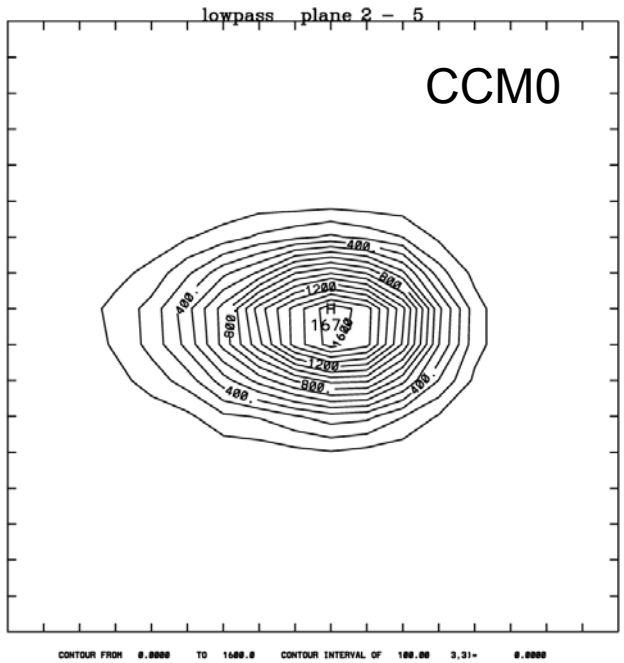



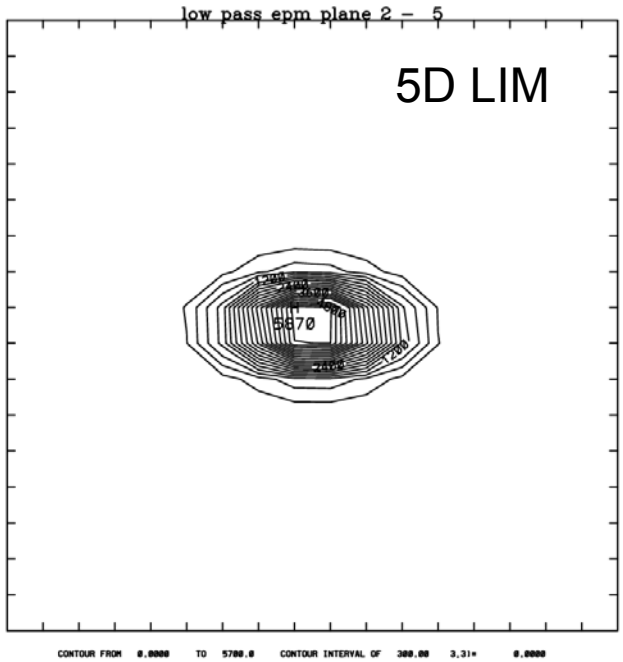



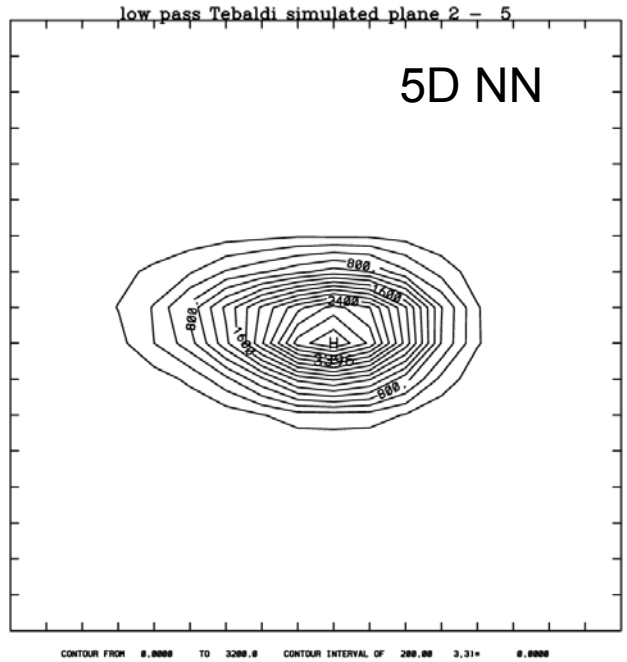



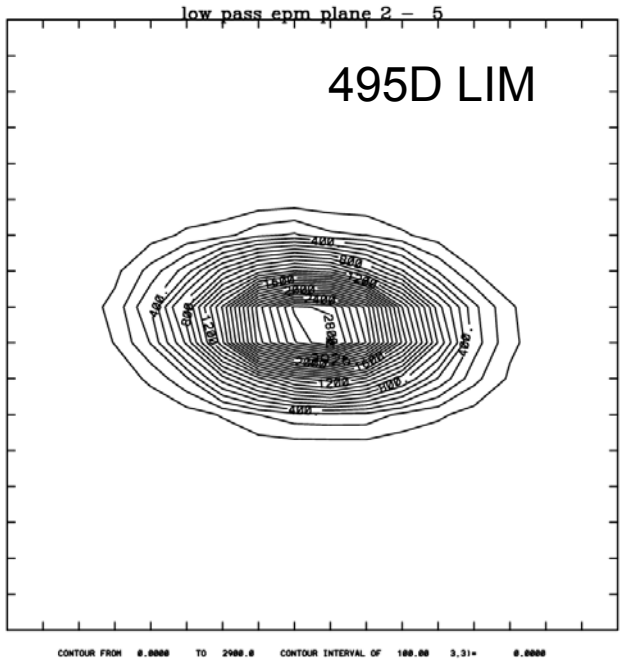



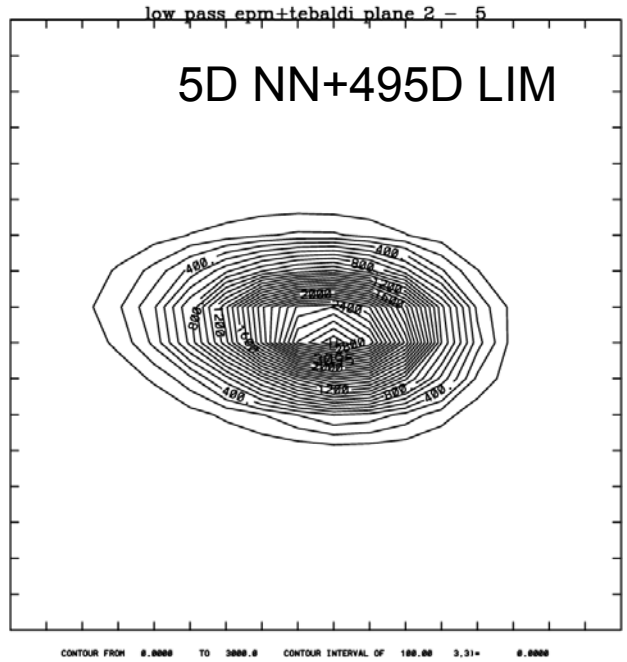
PDFs of 30d means in plane 2-5



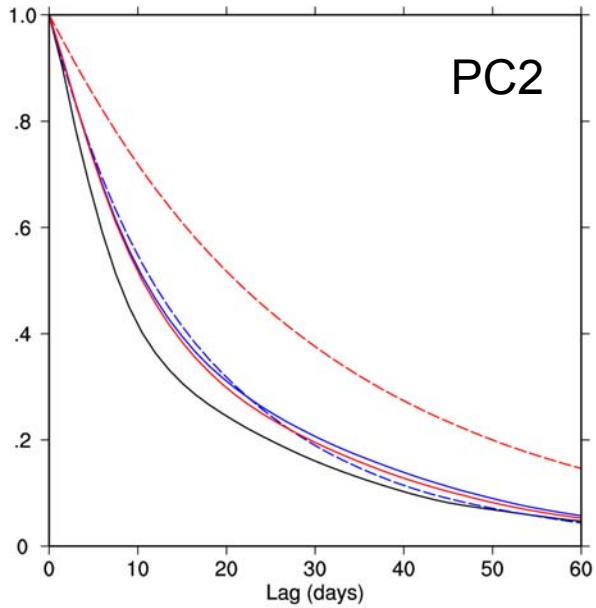



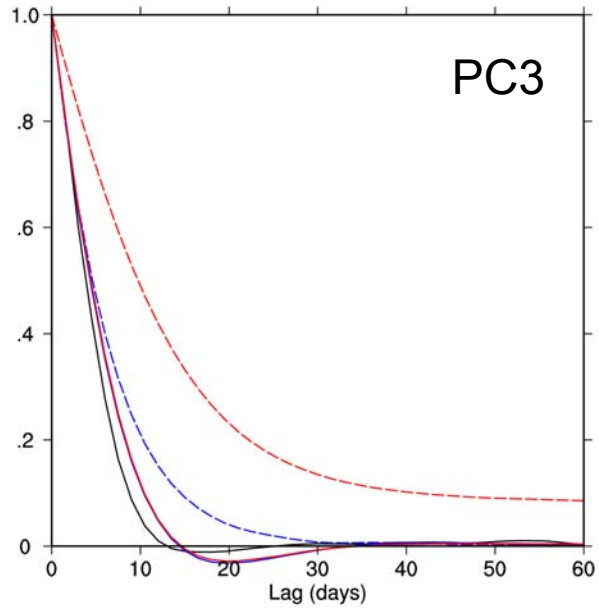



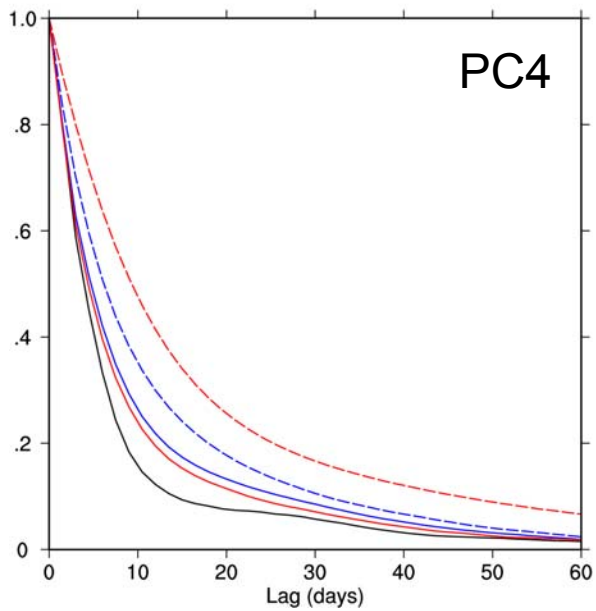



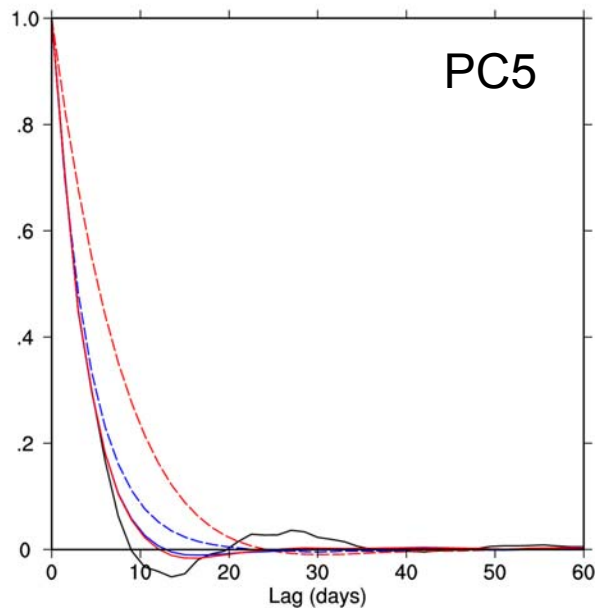



# lag correlations




**CCM0**

Neural Net

5D LIM

495D LIM

NN + 495D LIM