Scale-specic patterns of phase coherence between solar/geomagnetic activity and climate variability

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Understanding complex dynamics

Search for

- hidden regularities
- repetitive patterns
- oscillatory phenomena

Study of interactions

- clues to complex behaviour
- facts for model building
- characterization - diagnostics

SSA - Singular system (or singular spectrum) analysis in its original form (also known as principal component analysis, or Karhunen-Loève decomposition) is a method for identification and distinction from noise of important information in multivariate data.

It is based on an orthogonal decomposition of a covariance matrix of multivariate data under study.

Monte Carlo SSA:

DETECTION -> HYPOTHESIS TESTING

DISCRIMINATING STATISTIC

STANDARD: POWER (EIGENVALUES)

ENHANCED: REGULARTITY INDEX

NULL HYPOTHESIS

1/f … as AR1, 1/f … spectrum fitting

1/f, LRD, multifractal …

randomization in wavelet domain

ELSEVIER

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PHYSICA D

Coarse-grained entropy rates for characterization of complex time series

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Abstract

A method for classification of complex time series using coarse-grained entropy rates (CER's) is presented. The CER's, which are computed from information-theoretic functionals - redundancies, are relative measures of regularity and predictability, and for data generated by dynamical systems they are related to Kolmogorov–Sinai entropy. A deterministic dynamical origin of the data under study, however, is not a necessary condition for the use of the CER's, since the entropy rates can be defined for stochastic processes as well. Sensitivity of the CER's to changes in data dynamics and their robustness with respect to noise are tested by using numerically generated time series resulted from both deterministic – chaotic and stochastic processes. Potential application of the CER's in analysis of physiological signals or other complex time series is demonstrated by using examples from pharmaco-EEG and tremor classification.

MONTHLY AVERAGE NEAR-SURFACE AIR TEMPERATURE

PRAGUE – KLEMENTINUM STATION

9 OTHER EUROPEAN STATIONS

MONTHLY NORTH ATLANTIC OSCILLATION INDEX

http://www.cru.uea.ac.uk/cru/data/nao.htm

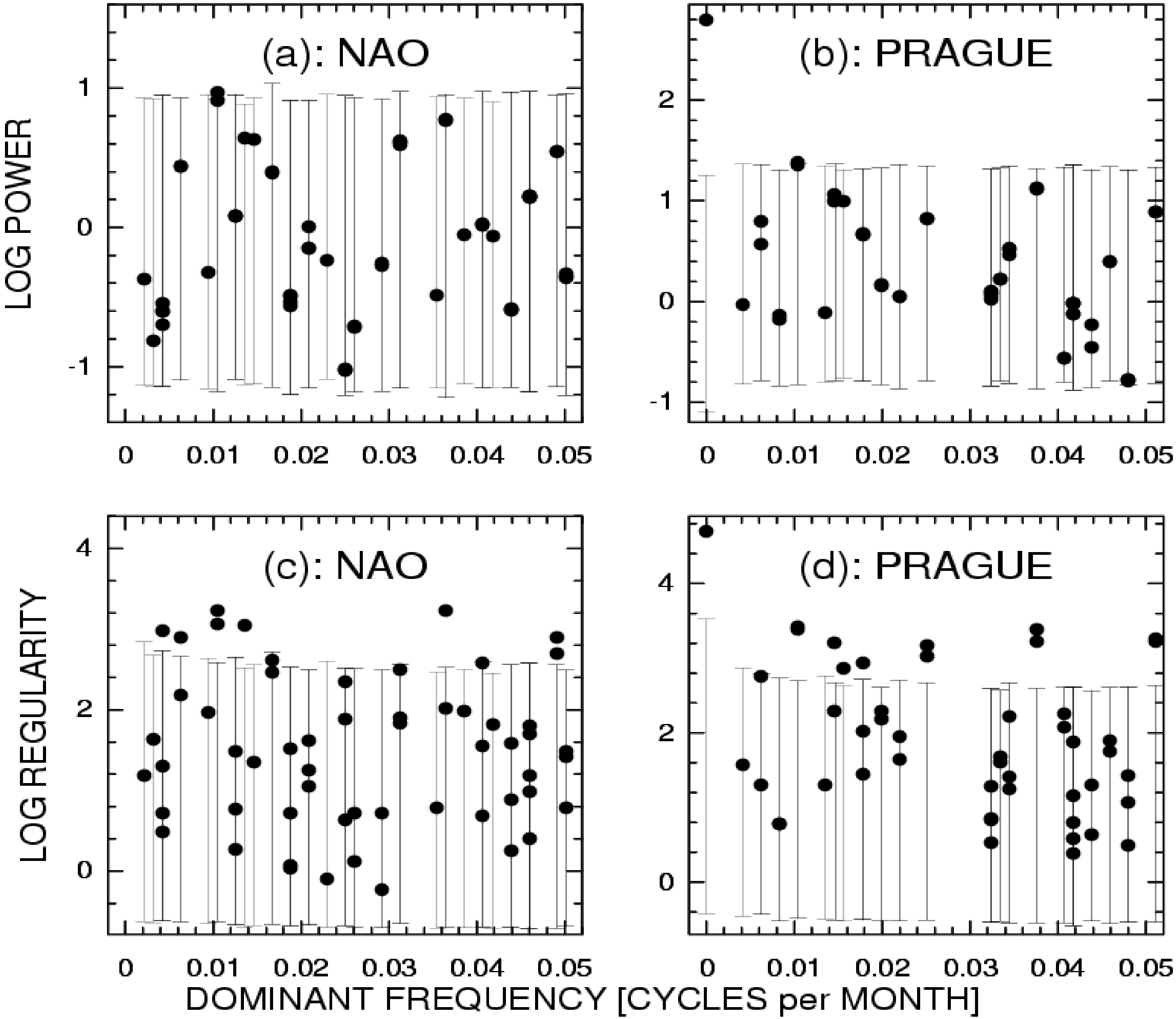
MONTHLY aa INDEX

World Data Centre for Solar-Terrestrial Physics, Chilton

http://www.ukssdc.ac.uk/data/wdcc1/wdc_menu.html

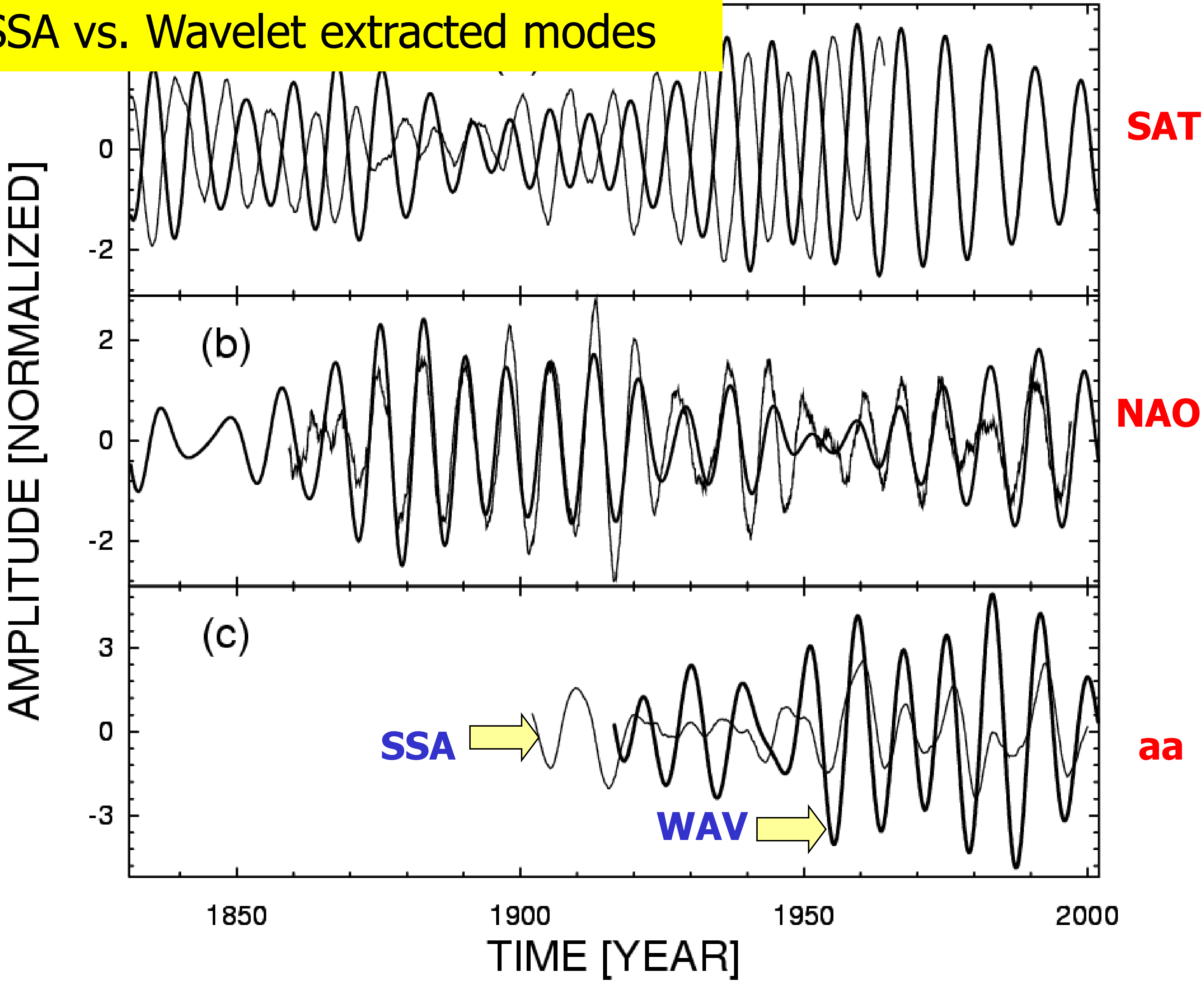
MONTHLY SUNSPOT NUMBERS

http://sidc.oma.be/DATA/monthssn.dat


(a): NAO
(b): PRAGUE
(c): NAO
(d): PRAGUE
LOG POWER
LOG REGULARITY
DOMINANT FREQUENCY [CYCLES per MONTH]
0
0.01
0.02
0.03
0.04
0.05
-1
1
2
4

Source data	Period [years]			
	≈ 11	$7-8$	≈ 5.5	≈ 2.2
sunspots	+	+	−	+
aa	+	+	+	−
T	−	+	+	+
NAO	−	+	−	+

SSA vs. Wavelet extracted modes



Instantaneous phases of the oscillatory modes

Analytic signal $\psi(t)$ is a complex function of time

$$\psi(t) = s(t) + j\hat{s}(t) = A(t)e^{j\phi(t)}. \tag{8}$$

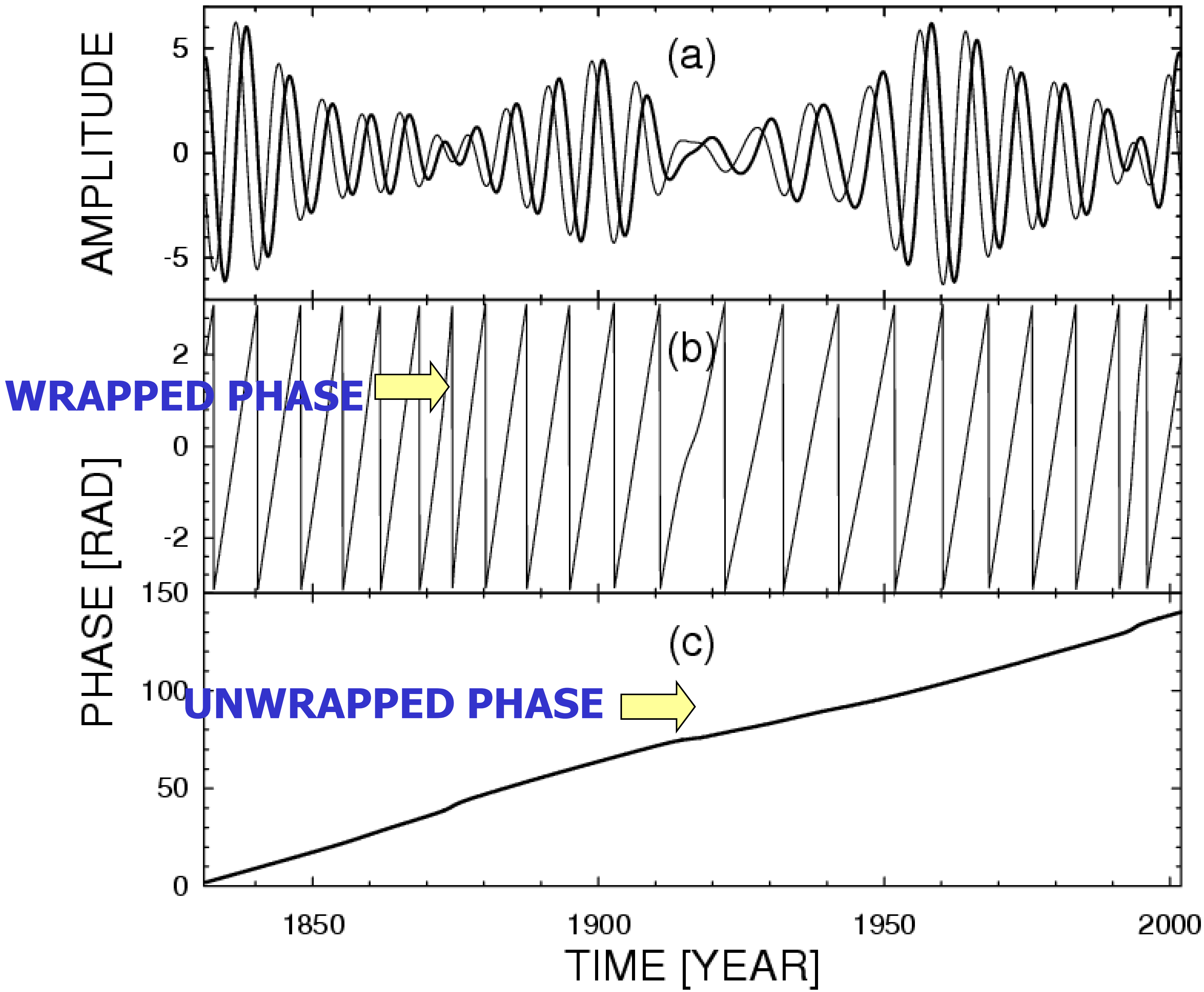
$\hat{s}(t)$ – Hilbert transform of $s(t)$

$$\hat{s}(t) = \frac{1}{\pi}\,\text{P.V.}\int_{-\infty}^{\infty}\frac{s(\tau)}{t-\tau}d\tau. \tag{9}$$

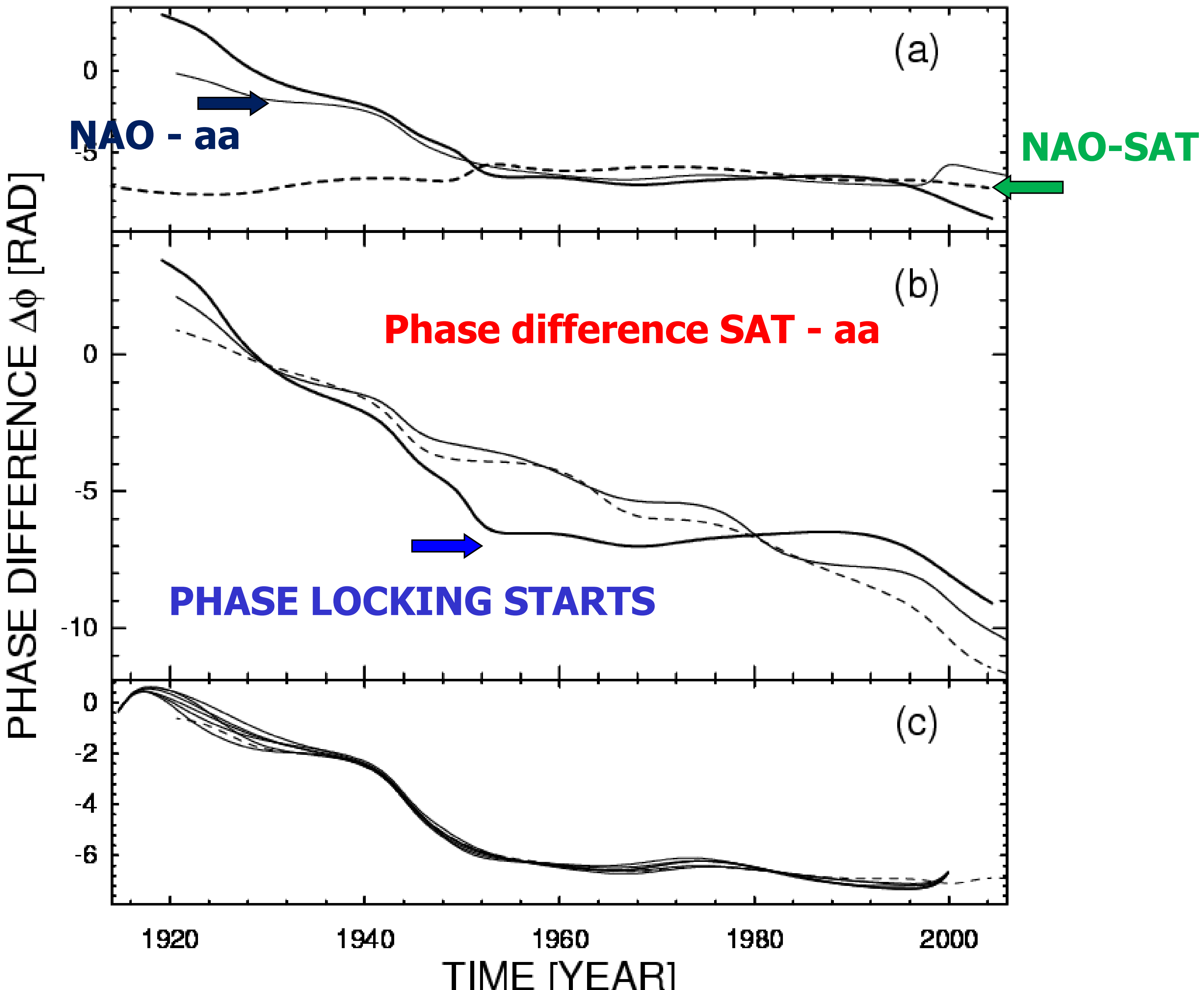
instantaneous phase $\phi(t)$ of the signal $s(t)$ is

$$\phi(t) = \arctan\frac{\hat{s}(t)}{s(t)}. \tag{10}$$

For SSA modes, each oscillatory mode usually exists together with its orthogonal ($\pi/2$-delayed or advanced) version. These two modes can be considered as the real and imaginary parts of the analytic signal.



AMPLITUDE
(a)
5
0
-5
(b)
2
0
-2
WRAPPED PHASE
PHASE [RAD]
150
(c)
100
UNWRAPPED PHASE
50
0
1850
1900
1950
2000
TIME [YEAR]



(a)
NAO - aa
NAO-SAT
(b)
Phase difference SAT - aa
PHASE LOCKING STARTS
(c)
PHASE DIFFERENCE Δφ [RAD]
0
-5
-10
-2
-4
-6
1920
1940
1960
1980
2000
TIME [YEAR]

Phase synchronization:

Mean Phase Coherence (Mean Resultant Length):

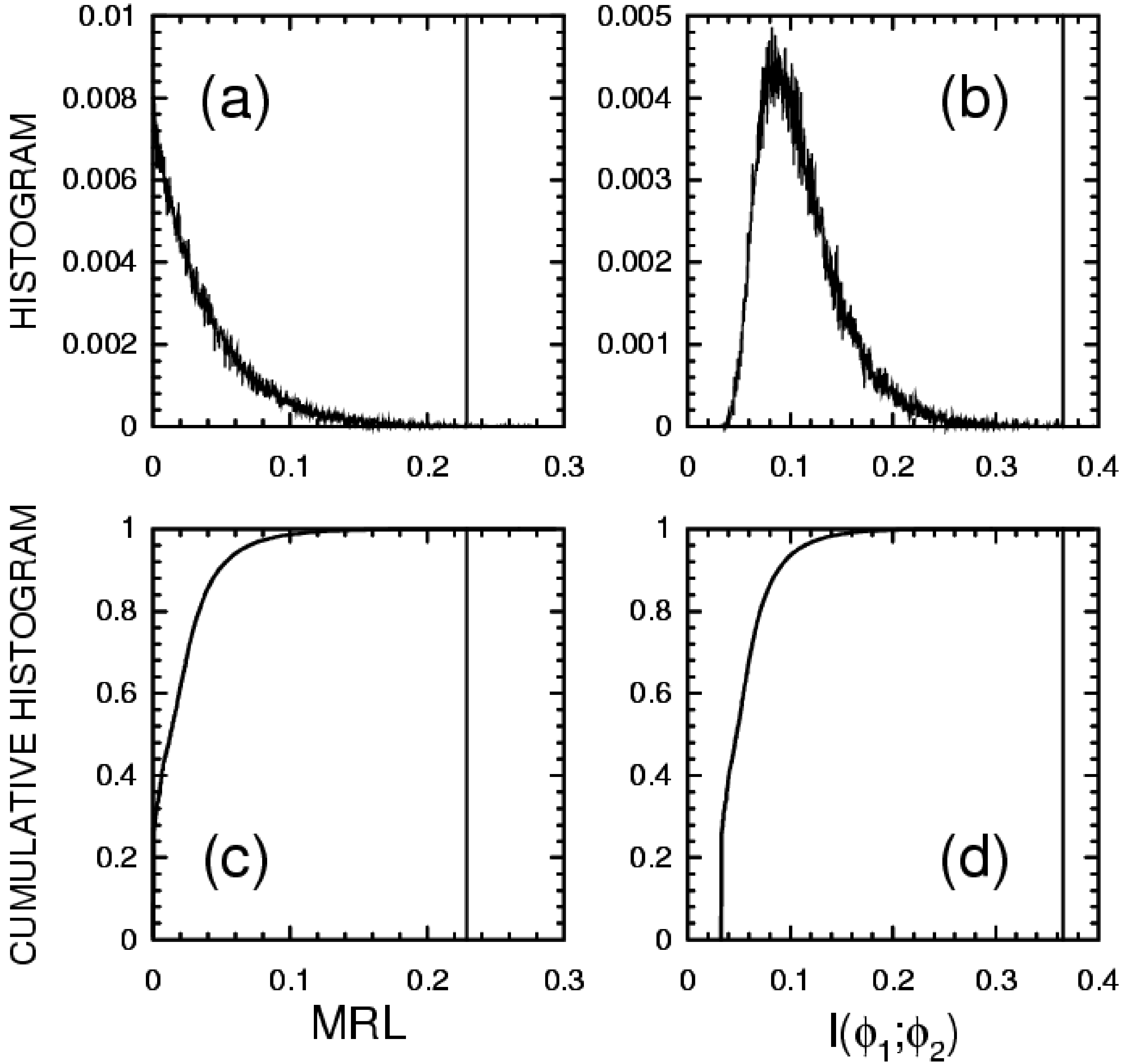
$$\gamma^2 = \langle \cos(\Delta\psi(\mathrm{t})) \rangle^2 + \langle \sin(\Delta\psi(\mathrm{t})) \rangle^2$$

Mutual Information: $I(\phi_1;\phi_2)$

Testing using surrogate data:

- univariate and bivariate isospectral (FFT) surrogates
- permutation surrogates

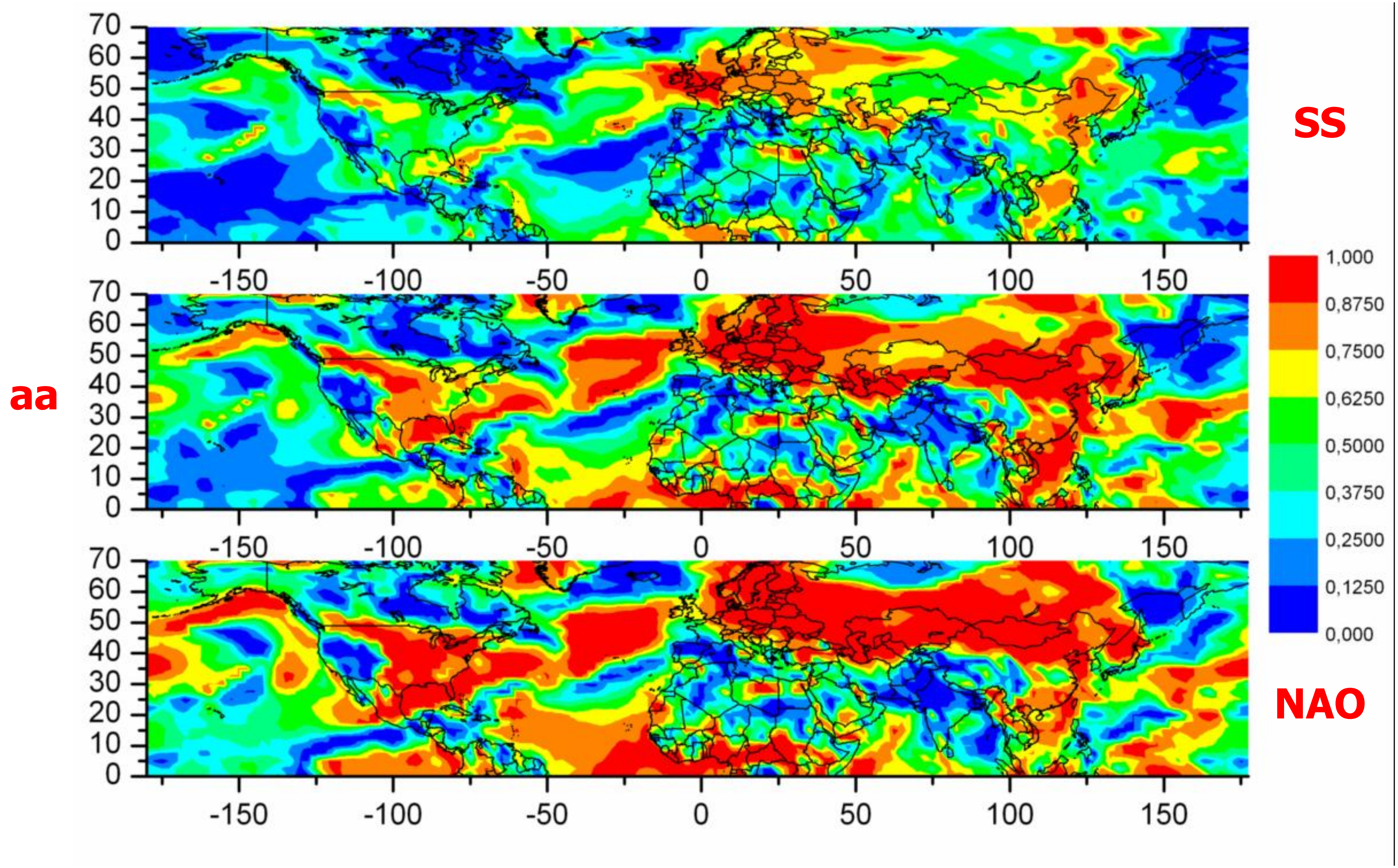
TESTING PHASE SYNCHRONIZATION



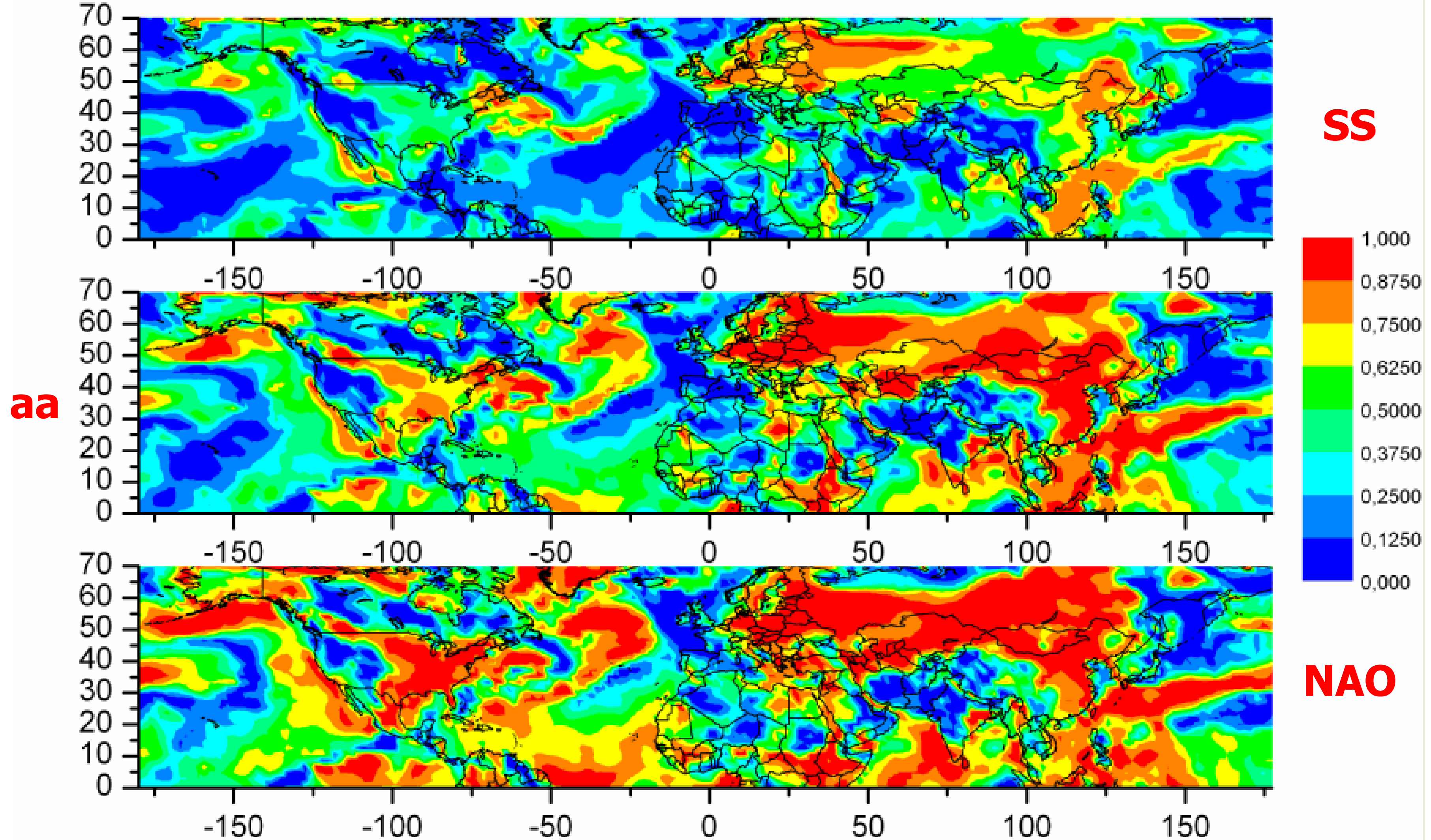
SPATIAL PATTERNS OF PHASE COHERENCE USING NCEP/NCAR AND ERA-40 REANALYSIS DATA

MEAN PHASE COHERENCE NORTHERN HEMISPHERE

PHASE COHERENCE OF ERA-40 SAT with



PHASE COHERENCE OF NCEP/NCAR SAT with



SPATIAL PATTERNS OF PHASE COHERENCE
ERA-40

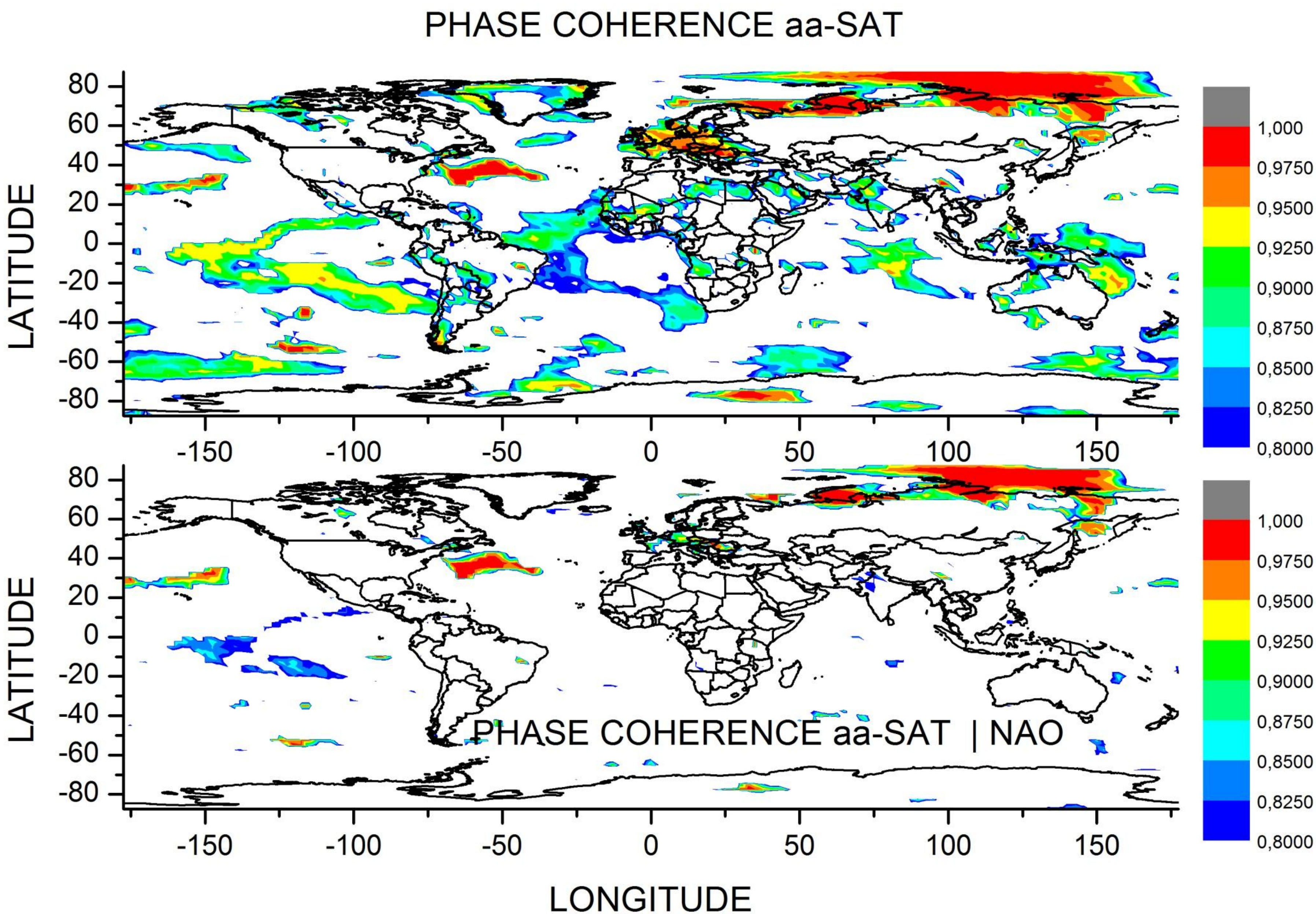
REANALYSIS DATA

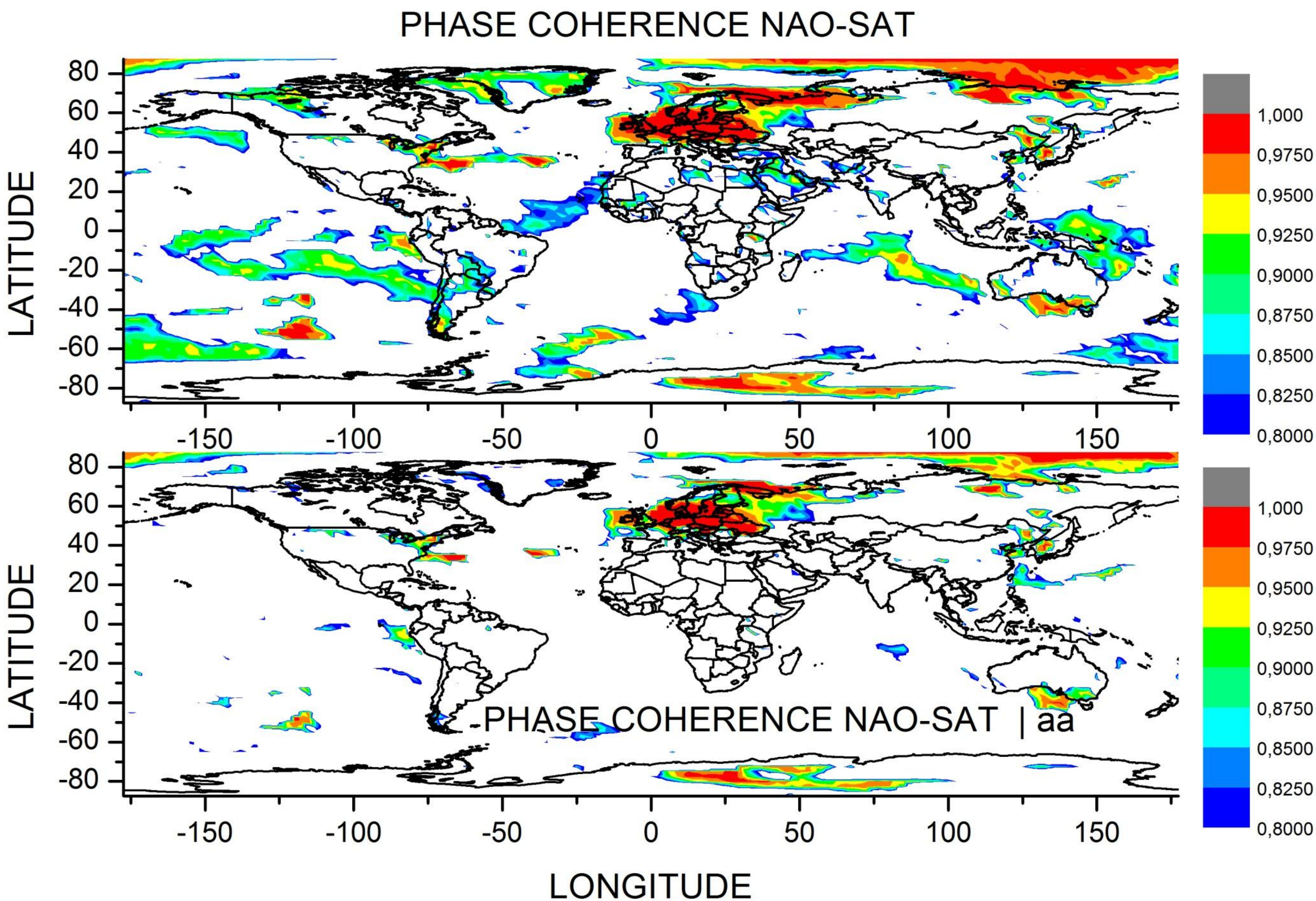
MUTUAL INFORMATION

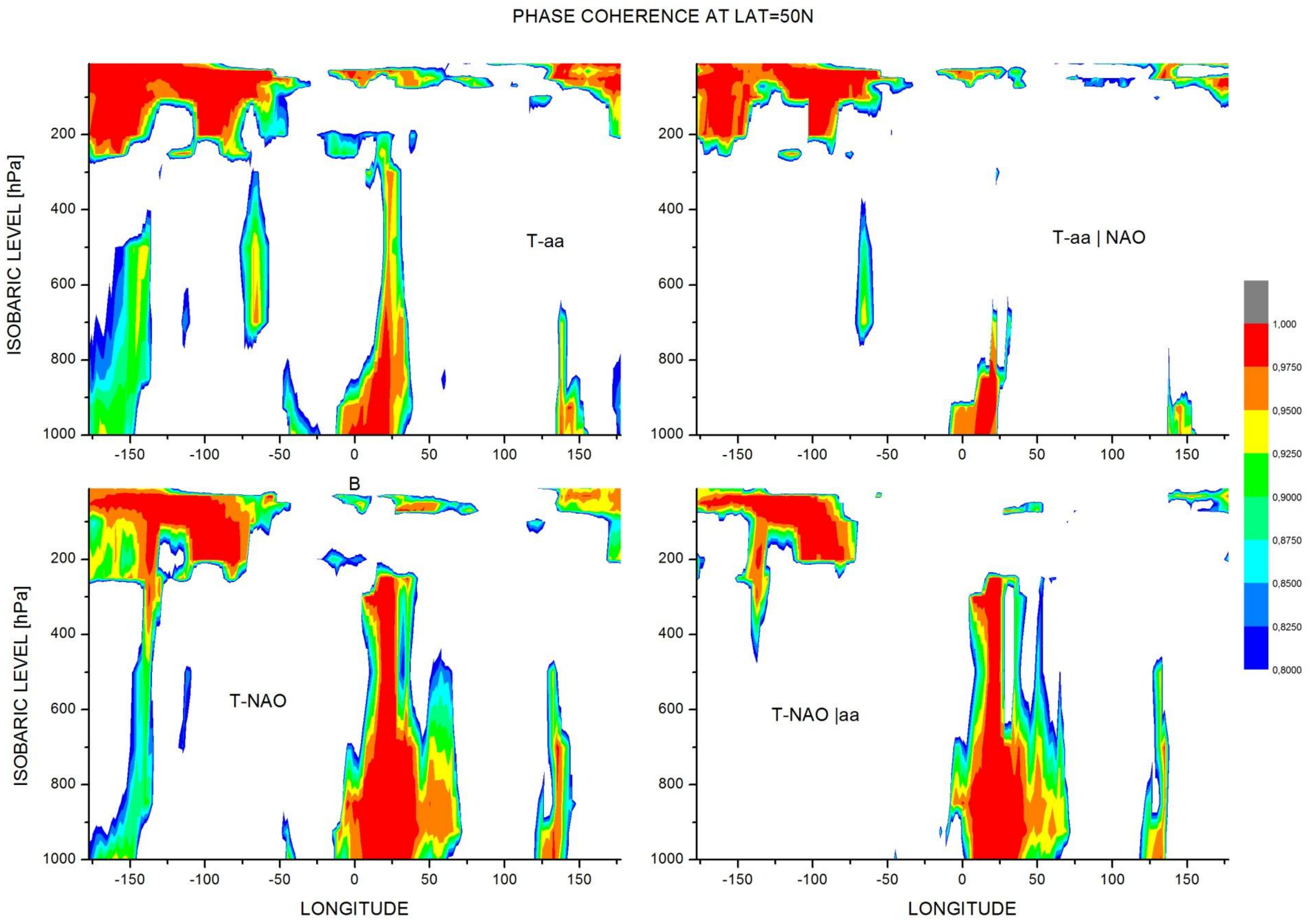
CONDITIONAL MUTUAL INFORMATION

SIGNIFICANCE

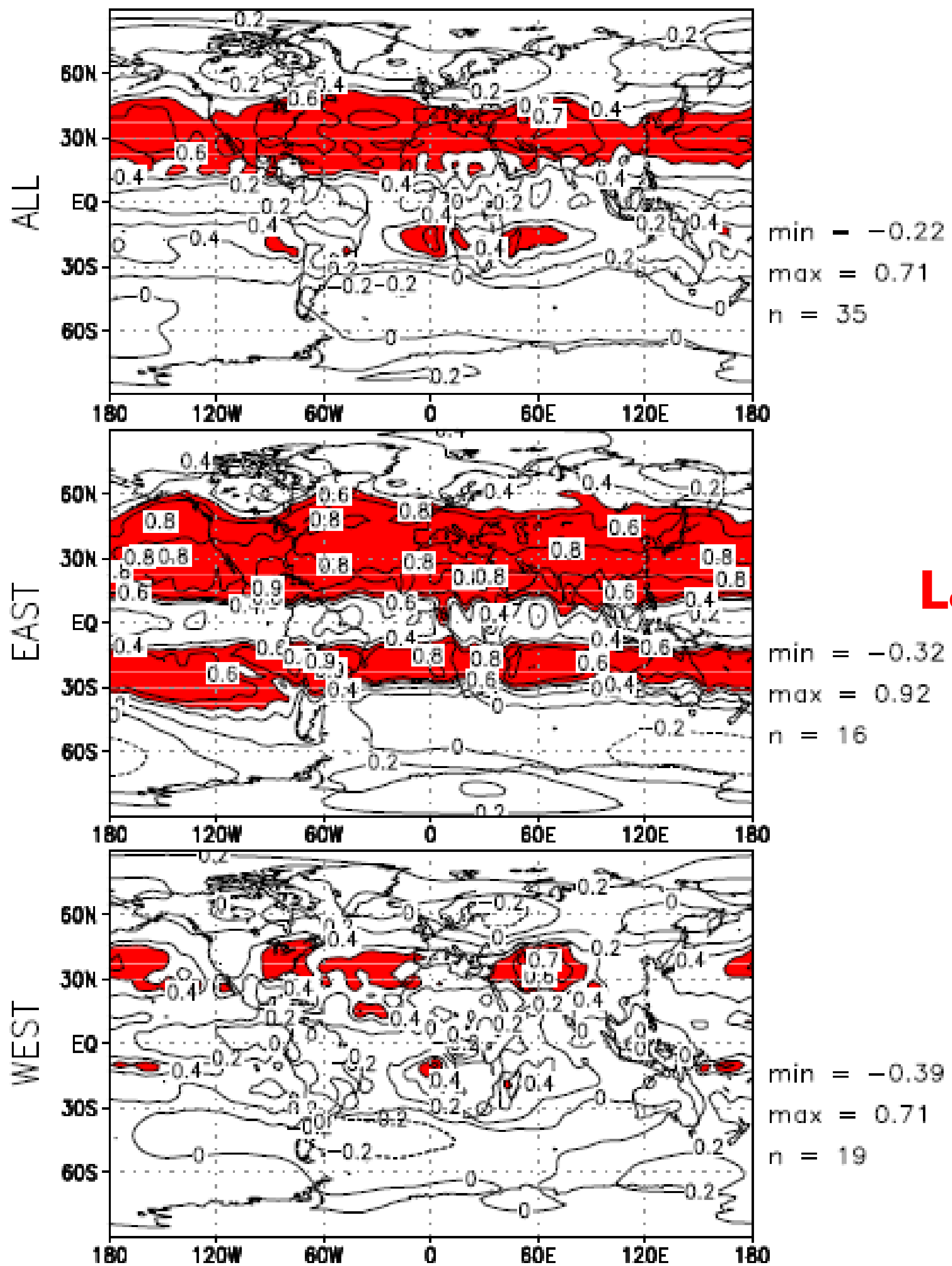
>PERCENTILE OF FT SURROGATE DISTRIBUTION


PHASE COHERENCE aa-SAT
LATITUDE
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
1,000
0,9750
0,9500
0,9250
0,9000
0,8750
0,8500
0,8250
0,8000
PHASE COHERENCE aa-SAT | NAO
LONGITUDE

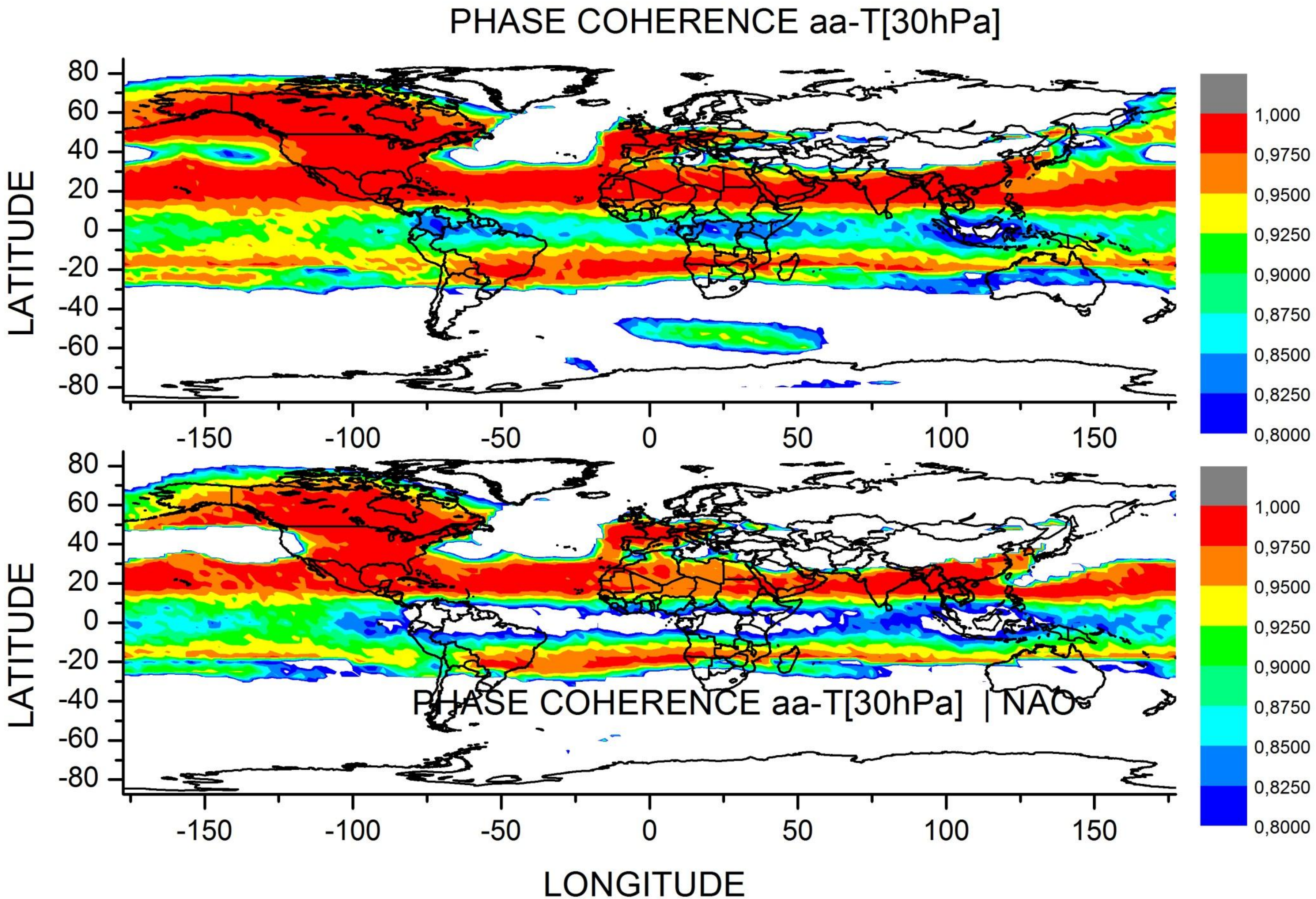

PHASE COHERENCE NAO-SAT
LATITUDE
LONGITUDE
PHASE COHERENCE NAO-SAT | aa
1,000
0,9750
0,9500
0,9250
0,9000
0,8750
0,8500
0,8250
0,8000



PHASE COHERENCE AT LAT=50N
T-aa
T-aa | NAO
B
T-NAO
T-NAO |aa
ISOBARIC LEVEL [hPa]
LONGITUDE
200
400
600
800
1000
-150
-100
-50
0
50
100
150
1,000
0,9750
0,9500
0,9250
0,9000
0,8750
0,8500
0,8250
0,8000



From Labitzke, 2004


PHASE COHERENCE aa-T[30hPa]
LATITUDE
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
1,000
0,9750
0,9500
0,9250
0,9000
0,8750
0,8500
0,8250
0,8000
PHASE COHERENCE aa-T[30hPa] | NAO
LONGITUDE

Statistical evidence for coupling between solar/geomagnetic activity and climate variability has been obtained from continuous monthly data, independent of the season, QBO, however, confined to the temporal scale related to oscillatory periods about 7--8 years.

7-8yr CYCLES IN

NAO, TEMPERATURE, GEOMAGNETIC aa INDEX AND SUNSPOT NUMBERS ARE

PHASE COHERENT FROM 1950's TO 1990's

ATMOSPHERE/CLIMATE – SOLAR/GEOMAG ACTIVITY

DIFFERENT PHENOMENA

TRANSIENTLY PHASE SYNCHRONIZED ?

RELATIVE VARIANCE (OF TOTAL VARIANCE OF e.g. TEMPERATURE)

HARD TO ESTIMATE/DEPENDS ON SSA/WAVELET PARAMETERS

BUT RELATIVELY **SMALL**

PHYSICAL MECHANISMS?

INTERSCALE RELATIONS ?

i.e., CAN A CYCLE ON A SCALE DRIVE LESS COHERENT VARIABILITY

ON OTHER SCALES ?

FURTHER SOPHISTICATED TESTING REQUIRED

19 September 1994

PHYSICS LETTERS A

ELSEVIER

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Testing for nonlinearity in weather records

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Abstract

Daily records of atmospheric surface pressure, temperature and geopotential heights of 500 hPa isobaric level were tested for nonlinearity, the necessary condition for deterministic chaos, using redundancy and surrogate data techniques. While the time series of the temperature and the geopotential heights were found indiscernible to be from correspondent isospectral linear stochastic processes, a significant nonlinear component was detected in the dynamics of the pressure recording, however, no specific signatures of low-dimensional chaos were manifest.

Thank you for your attention.

http://www.cs.cas.cz/mp

➡ Electronic preprints

Nonlinear Dynamics Group

http://ndw.cs.cas.cz