Mechanisms triggering the 1976-77 regime shift in the North Pacific.

Katerina Giamalaki
ag2e13@soton.ac.uk

Claudie Beaulieu (UoS)
Stephanie Henson (NOCS)
Davide Faranda (LSCE/IPSL)
Adrian Martin (NOCS)
Simon Josey (NOCS)
Introduction
• Regime Shifts
• Shift Area
• Hypothesis

1. Did an extreme atmospheric event initiate the shift?
   • Dynamical Systems Analysis

2. Were there sudden changes in net heat flux that maintained the shift?
   • Empirical Orthogonal Functions (EOFs) & Environmental change-point detection analysis (EnvCpt)

How is everything connected? - Conclusions
Regime Shifts

• Abrupt changes
• High - amplitude variability
• Propagation through trophic levels
• Leading to ecosystem restructuring

http://www.thenakedscientists.com/HTML/articles/article/brucewrightcolumn1.htm
Positive PDO - Atmosphere

- Positive PDO
- NPI

Aleutian Low
North Pacific High

SST
Positive PDO – Ocean

- Oyashio Current
- Alaska Current
- North Pacific Current
- Kuroshio Current
- North Equatorial Current
- California Current
- Equatorial Countercurrent
What caused the 1977 shift?

Examine the potential of dynamical and statistical analyses to reveal new insights.

Test the hypothesis:

- Extreme atmospheric event $\rightarrow$ forcing
- Changes in heat budget $\rightarrow$ maintenance
1. Did an extreme atmospheric event initiate the shift?
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How is everything connected? - Conclusions
Dynamical system analysis

- **Sea Level Pressure (SLP)**
  - Daily from January 1948 to August 2016
  - National Centre for Environmental Prediction/National Centre for Atmospheric Research (NCEP/NCAR) reanalysis 2.5°x2.5°

- **Calculation of instantaneous properties:**
  - Instantaneous dimension $d(\zeta)$
  - Persistence $\theta(\zeta)$

(Faranda et al. 2017)
Instantaneous Properties

\[ \zeta_1 \text{ (a state of the system)} \]

\[ \text{Field value} \]

\[ \text{Daily SLP pattern} \]

\[ \theta(\zeta) = \text{indicator of the persistence time of each } \bullet \]

\[ d(\zeta) = \text{number of degrees of freedom for each } \bullet \]
Extreme SLP patterns

- $d(\zeta)$ extreme low
- $\theta(\zeta)$ extreme high

Pa $\times 10^5$

1.015
1.01
1.005
1

Positive NPI
Negative NPI

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When did the extreme SLP happen?

- \(d(\zeta)\) extreme low
- \(\theta(\zeta)\) extreme high

![Diagrams showing the distribution of occurrences for different SLP conditions.](image-url)
Is 1977 different?

Average $d(\zeta)$ extreme low days per year = 5.3

94% of extreme days occur in winter (Jan-Feb)
Outline

- Introduction
  - Regime Shifts
  - Shift Area
  - The 1977 regime shift

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- How is everything connected? - Conclusions
Empirical Orthogonal Functions (EOFs)

- Identify large scale patterns governing the region

- Net heat flux
  - Winter averages from January 1948 to August 2016
  - NCEP/NCAR reanalysis 2.5°x2.5°
Any sudden changes in the net heat flux?

EOF 1: 22%

Abrupt change - 1979
Environmental change-point detection analysis (EnvCpt)

- Fits eight models
- Characterizes different types of variability
  - no changes
  - long-term trends
  - changes in mean/variance
  - changes in trend
  - short term memory
- Net heat flux (First EOF & Pixel-wise)
  - Winter averages from January 1948 to August 2016
  - NCEP/NCAR reanalysis 2.5°x2.5°

(Killick, Beaulieu and Taylor, 2016; https://cran.r-project.org/web/packages/EnvCpt/index.htm)
Any sudden changes in the net heat flux?

EnvCpt $\rightarrow$ 1st EOF of net heat flux

Trend cpt + AR(1)

Trend cpt

Mean cpt + AR(1)

Mean cpt

Trend + AR(1)

Trend

Mean + AR(1)

Mean

Data

AIC

More likely
Less likely

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Any sudden changes in the net heat flux?

Kuroshio – Oyashio Extension

EOF 1 – Net heat flux

Number of pixels per year

Longitude

Latitude

140 160 180

40 35 30

30 40

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How is everything connected? - Conclusions
How is everything connected?

1. Aleutian Low deepening
2. Westerlies and Southerlies increase
3. SST increase - Ekman downwelling
4. SST decrease - cold air advection
5. Rossby waves
6. Downward heat fluxes increase
Conclusions

- Novel approaches including Dynamical System and Change-point Detection Analyses showing:
  - Statistical evidence that an extreme Aleutian Low occurred in winter 1976-77;
  - Strongest and most persistent Aleutian Low throughout the whole study period;
  - Abrupt changes detected in the Kuroshio-Oyashio Extension region centred around the year 1977.

ag2e13@soton.ac.uk