Barents Sea Atlantification Driven by a Shift in Atmospheric Synoptic Time Scale

BCPU, March 13th 2026

Robinson Hordoir [1,2] Vahidreza Jahanmard [3] Pål Erik Isachsen [4,5] Ulrike Löptien [6]
Heiner Dietze [6] Andrea Gierisch [7] Anne Britt Sandø [1,2] Nicole Delpech-Ellmann [3]
Vidar Lien [1,2]

[1]Institute of Marine Research, Bergen [2]Bjerknes Centre for Climate Research, Bergen [3]Department of Civil Engineering and Architecture, Tallinn University of Technology [4]Department of Geosciences, University of Oslo [5]Norwegian Meteorological Institute, Oslo [6]University of Kiel, Germany [7]Danish Meteorological Institute, Copenhagen

Outline

Analysis of a Nemo-NAA10km simulation

The Barents Sea Opening Flux reproduced by AI (First Version)

Influence of (Linear) Trends

A Bouncing Experiment

Signal Processing and AI reconstruction (Second Version)

Conclusion

Outline

Analysis of a Nemo-NAA10km simulation

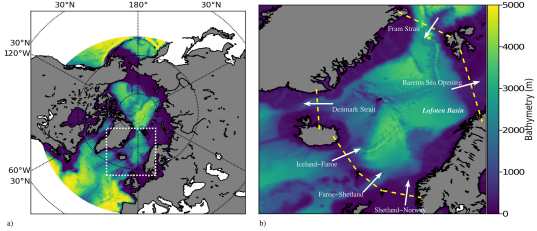
The Barents Sea Opening Flux reproduced by AI (First Version)

Influence of (Linear) Trends

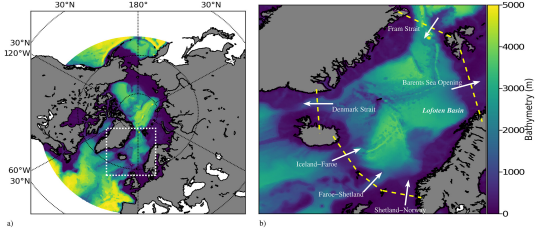
A Bouncing Experiment

Signal Processing and AI reconstruction (Second Version)

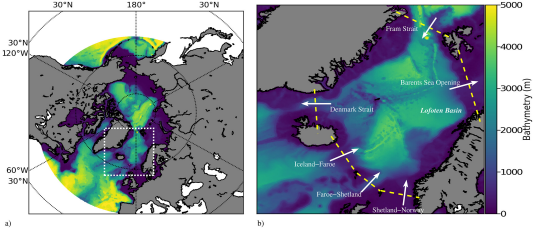
Conclusion



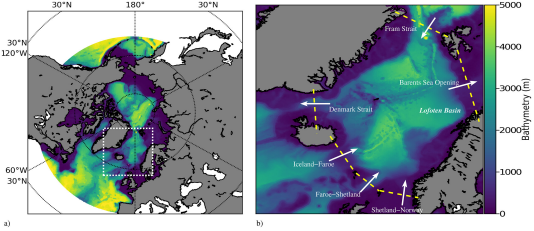
- Nemo-NAA10km is a forced ocean model for North Atlantic and Arctic oceans



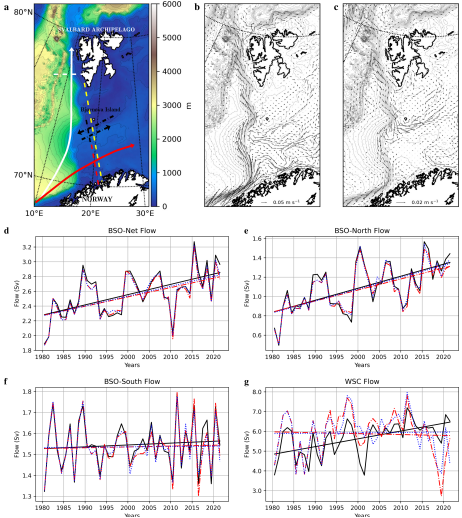
- Nemo-NAA10km is a forced ocean model for North Atlantic and Arctic oceans
- It is an ocean process model, without data assimilation or restoring of any kind



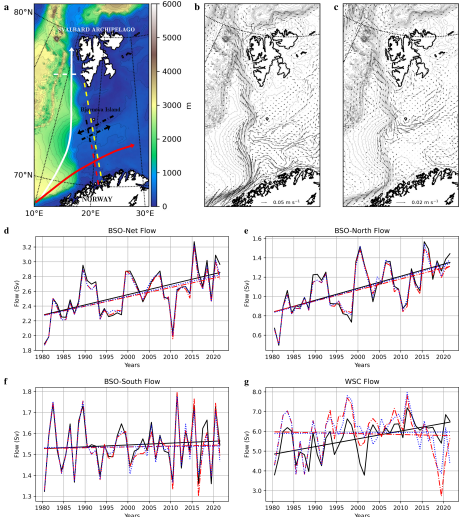
- Nemo-NAA10km is a forced ocean model for North Atlantic and Arctic oceans
- It is an ocean process model, without data assimilation or restoring of any kind
- All details in Hordoir et al. 2022, JGR Oceans



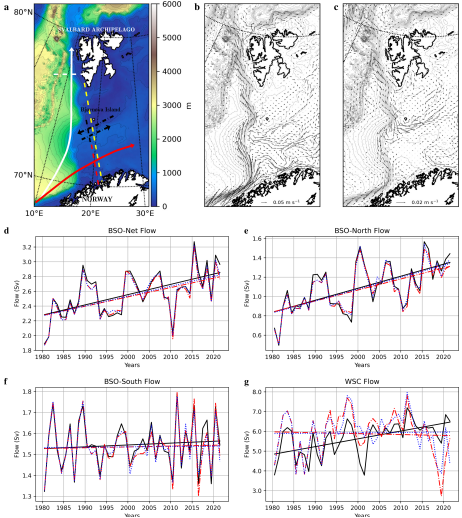
- Nemo-NAA10km is a forced ocean model for North Atlantic and Arctic oceans
- It is an ocean process model, without data assimilation or restoring of any kind
- All details in Hordoir et al. 2022, JGR Oceans
- We compute barotropic flows at the Nordic Sea gates for the period 1975-2021



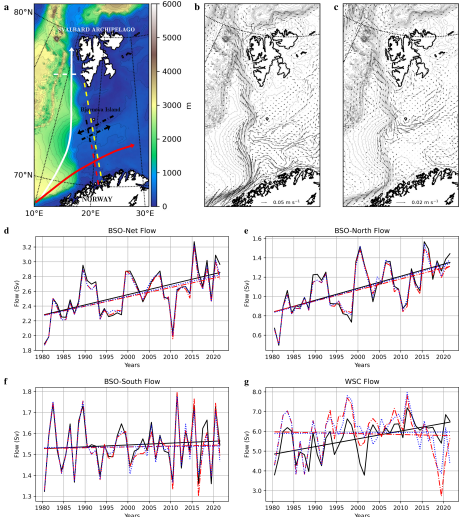
- Obvious trend at Barents Sea Opening



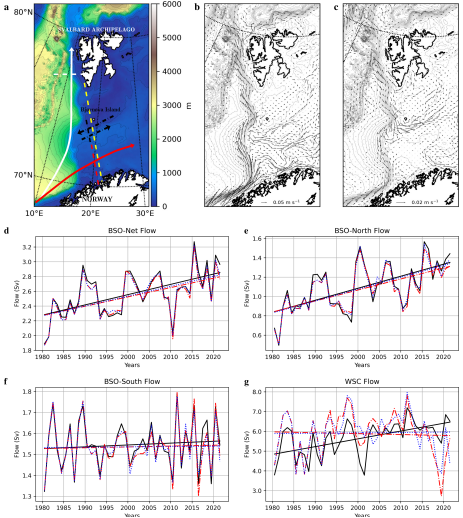
- Obvious trend at Barents Sea Opening
- There is a decrease of the outflow of the Barents towards the Nordic Seas



- Obvious trend at Barents Sea Opening
- There is a decrease of the outflow of the Barents towards the Nordic Seas
- Not only in our model, but also other models, observations etc...



- Obvious trend at Barents Sea Opening
- There is a decrease of the outflow of the Barents towards the Nordic Seas
- Not only in our model, but also other models, observations etc...
- Many papers try to explain, many correlations etc... but no clear causation link



- Obvious trend at Barents Sea Opening
- There is a decrease of the outflow of the Barents towards the Nordic Seas
- Not only in our model, but also other models, observations etc...
- Many papers try to explain, many correlations etc... but no clear causation link
- Let's try to crack the puzzle, we attack from a different angle

Outline

Analysis of a Nemo-NAA10km simulation

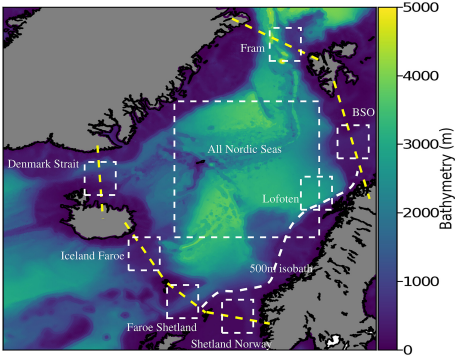
The Barents Sea Opening Flux reproduced by AI (First Version)

Influence of (Linear) Trends

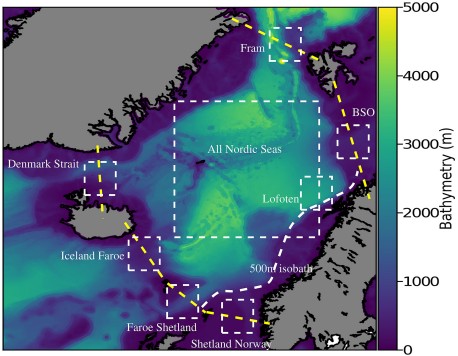
A Bouncing Experiment

Signal Processing and AI reconstruction (Second Version)

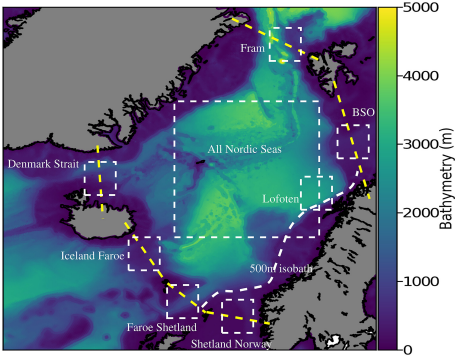
Conclusion



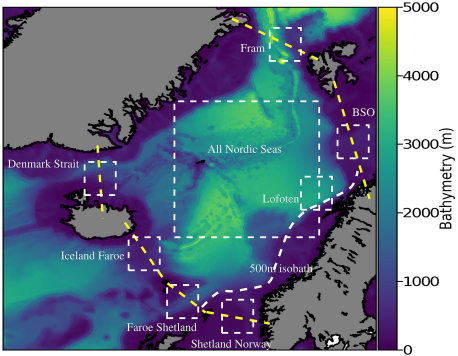
- Is it in the wind ?



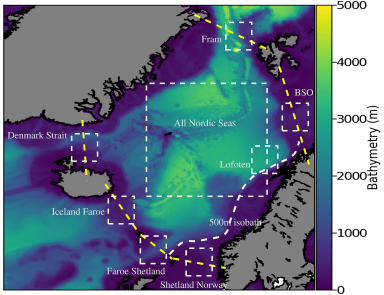
- Is it in the wind ?
- We compute wind indexes for each box, based on the Nemo-NAA10km forcing



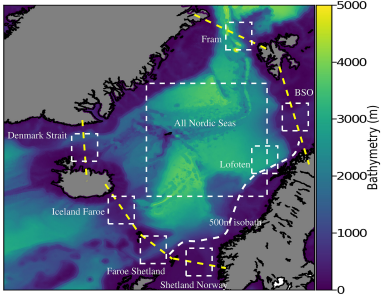
- Is it in the wind ?
- We compute wind indexes for each box, based on the Nemo-NAA10km forcing
- For each box, we compute spatially mean values of stress on u and v, and Svedrup transport



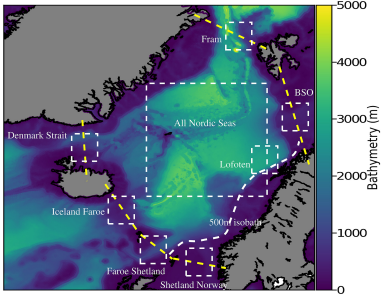
- Is it in the wind ?
- We compute wind indexes for each box, based on the Nemo-NAA10km forcing
- For each box, we compute spatially mean values of stress on u and v, and Svedrup transport
- We provide all this data to a deep learning (DL) algorithm, that will try to reconstruct the flow at Barents Sea Opening, simulated by Nemo-NAA10km, and based only on the past history of wind events



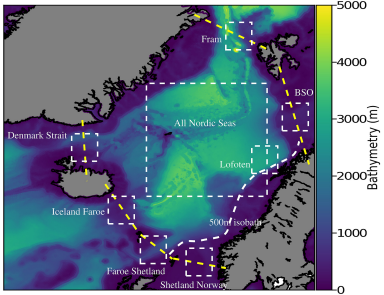
- First attempt with daily mean data



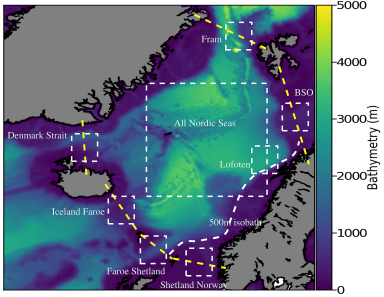
- First attempt with daily mean data
- Daily mean data for the forcing and daily mean data for the flow at Barents Sea Opening



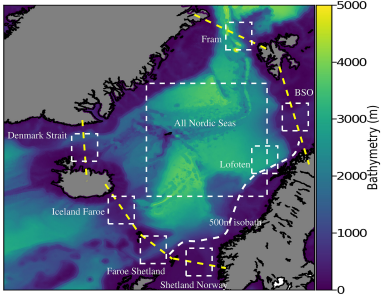
- First attempt with daily mean data
- Daily mean data for the forcing and daily mean data for the flow at Barents Sea Opening
- IT FAILS, the DL model can reconstruct the daily variability of the flow but the trend vanishes



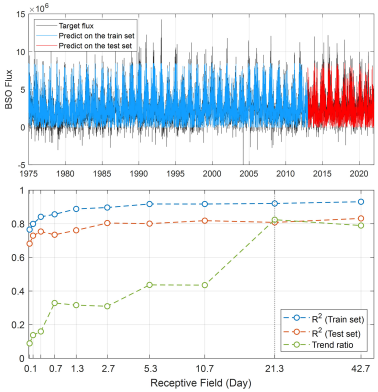
- First attempt with daily mean data
- Daily mean data for the forcing and daily mean data for the flow at Barents Sea Opening
- IT FAILS, the DL model can reconstruct the daily variability of the flow but the trend vanishes
- And then, almost by accident, we try hourly mean data



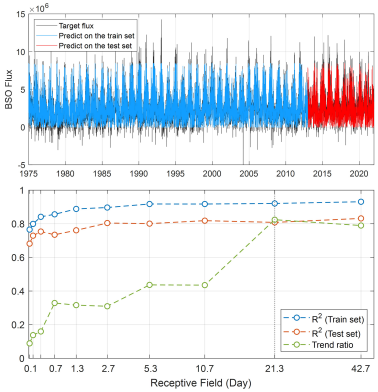
- First attempt with daily mean data
- Daily mean data for the forcing and daily mean data for the flow at Barents Sea Opening
- IT FAILS, the DL model can reconstruct the daily variability of the flow but the trend vanishes
- And then, almost by accident, we try hourly mean data
- Hourly mean data for the forcing and hourly mean for the flow at Barents Sea Opening



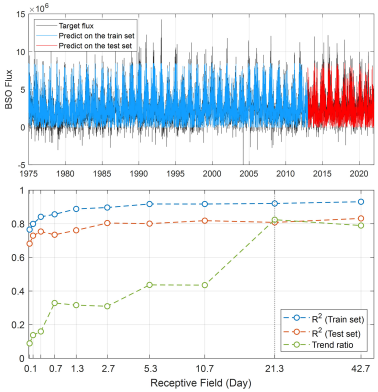
- First attempt with daily mean data
- Daily mean data for the forcing and daily mean data for the flow at Barents Sea Opening
- IT FAILS, the DL model can reconstruct the daily variability of the flow but the trend vanishes
- And then, almost by accident, we try hourly mean data
- Hourly mean data for the forcing and hourly mean for the flow at Barents Sea Opening
- And now... IT WORKS !! (???)



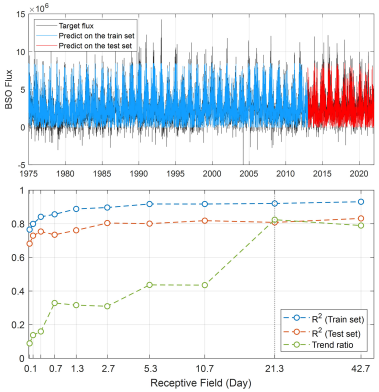
- The DL manages to reconstruct the BSO flow **with its trend**, based only on wind data provided as time series



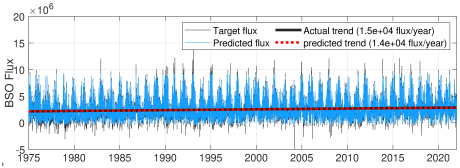
- The DL manages to reconstruct the BSO flow **with its trend**, based only on wind data provided as time series
- Important point, the DL does not aim at reconstructing the trend, it just appears in the reconstruction



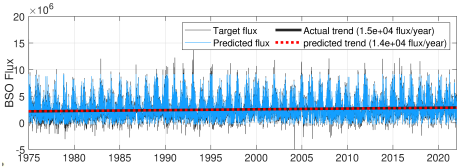
- The DL manages to reconstruct the BSO flow **with its trend**, based only on wind data provided as time series
- Important point, the DL does not aim at reconstructing the trend, it just appears in the reconstruction
- The wind data AND the BSO flow from Nemo-NAA10km need to be hourly values, it does not work with daily or lower frequency values



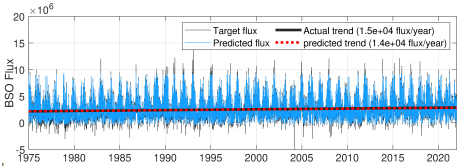
- The DL manages to reconstruct the BSO flow **with its trend**, based only on wind data provided as time series
- Important point, the DL does not aim at reconstructing the trend, it just appears in the reconstruction
- The wind data AND the BSO flow from Nemo-NAA10km need to be hourly values, it does not work with daily or lower frequency values
- For a given time, the BSO flow reconstruction requires wind data for the past 3 weeks



- The reconstruction reproduces the long term trend, based on wind data only



- The reconstruction reproduces the long term trend, based on wind data only
- So we jump to the simple conclusion that...



- The reconstruction reproduces the long term trend, based on wind data only
- So we jump to the simple conclusion that...
- There is a trend in wind data that can explain this, piece of cake, we will nail it soon...

Outline

Analysis of a Nemo-NAA10km simulation

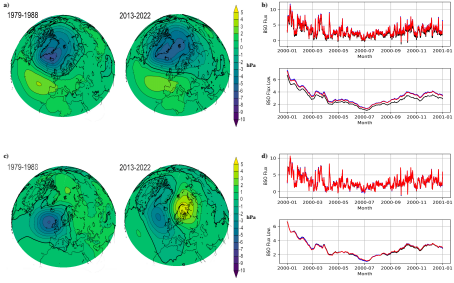
The Barents Sea Opening Flux reproduced by AI (First Version)

Influence of (Linear) Trends

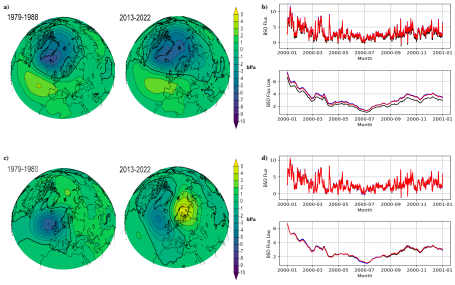
A Bouncing Experiment

Signal Processing and AI reconstruction (Second Version)

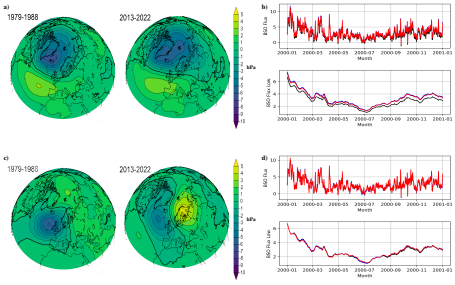
Conclusion



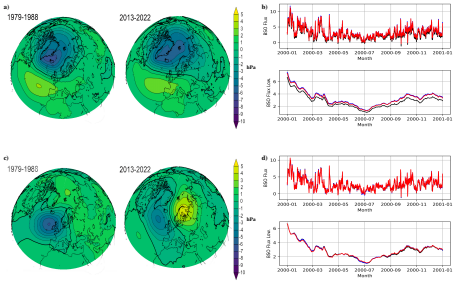
- Let's be a bit serious here, and forget about this DL stuff, DL is too spooky



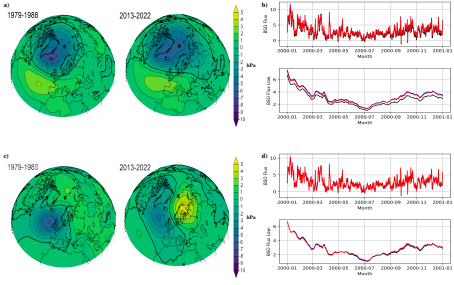
- Let's be a bit serious here, and forget about this DL stuff, DL is too spooky
- We compute EOFs of SLP of the principal variability modes for the North Atlantic and Arctic areas



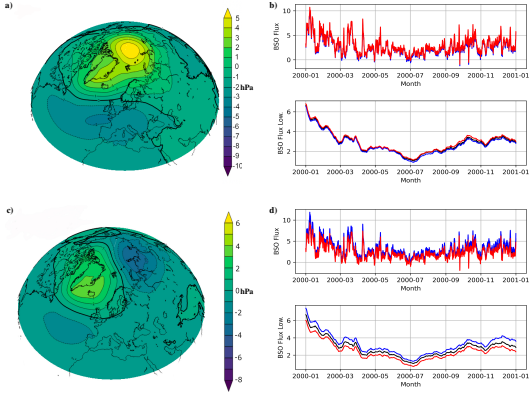
- Let's be a bit serious here, and forget about this DL stuff, DL is too spooky
- We compute EOFs of SLP of the principal variability modes for the North Atlantic and Arctic areas
- And we compute the trend for each EOF to create a modified atmospheric forcing dataset for year 2000



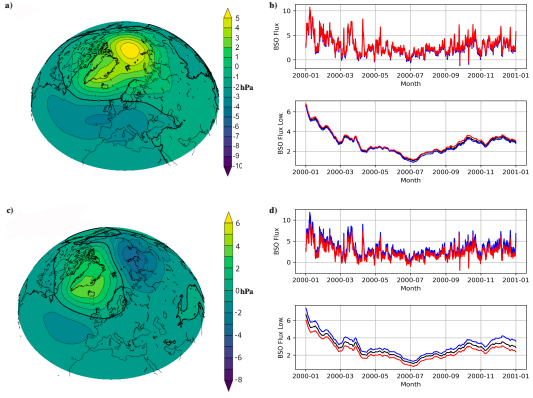
- Let's be a bit serious here, and forget about this DL stuff, DL is too spooky
- We compute EOFs of SLP of the principal variability modes for the North Atlantic and Arctic areas
- And we compute the trend for each EOF to create a modified atmospheric forcing dataset for year 2000
- And use it in Nemo-NAA10km to check the response...



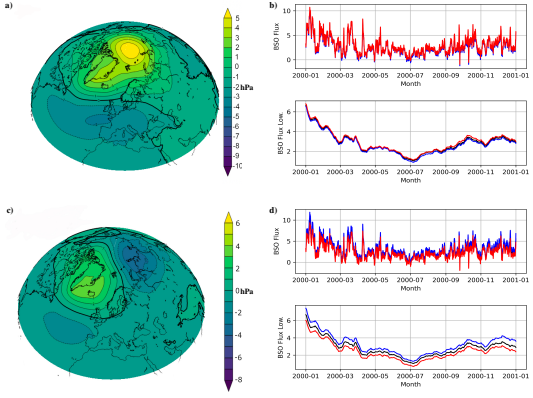
- Let's be a bit serious here, and forget about this DL stuff, DL is too spooky
- We compute EOFs of SLP of the principal variability modes for the North Atlantic and Arctic areas
- And we compute the trend for each EOF to create a modified atmospheric forcing dataset for year 2000
- And use it in Nemo-NAA10km to check the response...
- The trends in NAO and EA modes do not work to explain the flow trend, it must be in another mode over the Arctic



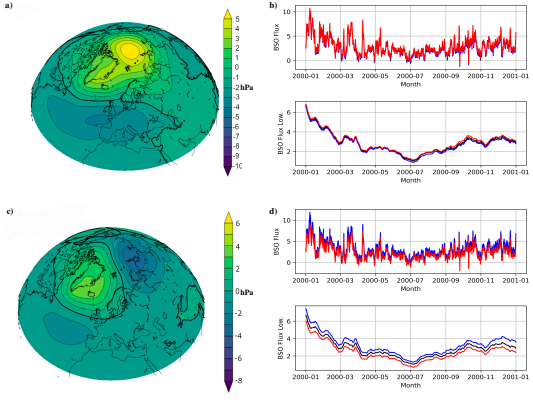
- For the Arctic Oscillation, we impose a positive Arctic Oscillation anomaly or negative one because the trend is very weak



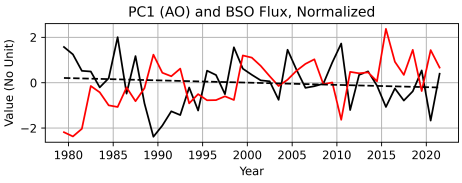
- For the Arctic Oscillation, we impose a positive Arctic Oscillation anomaly or negative one because the trend is very weak
- The response is very weak, so the real trend in Arctic Oscillation would produce an even weaker one



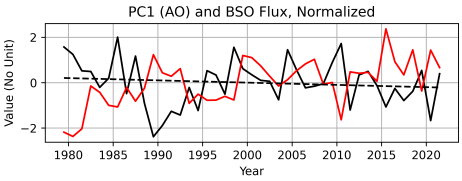
- For the Arctic Oscillation, we impose a positive Arctic Oscillation anomaly or negative one because the trend is very weak
- The response is very weak, so the real trend in Arctic Oscillation would produce an even weaker one
- So the trend in Arctic Oscillation can not explain the BSO flow trend

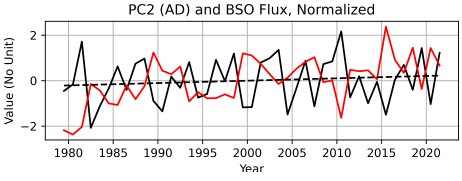


- The Arctic Dipole has a strong influence on the BSO flow

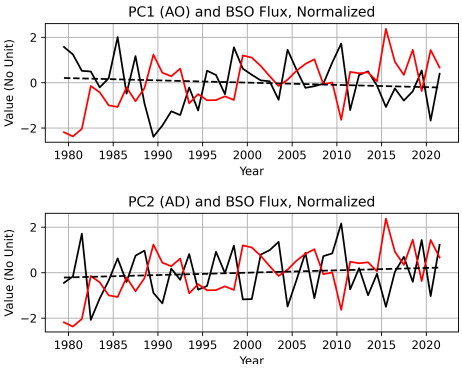


- But the Arctic Dipole trend goes in the wrong direction, and is obviously anti-correlated with the BSO flow

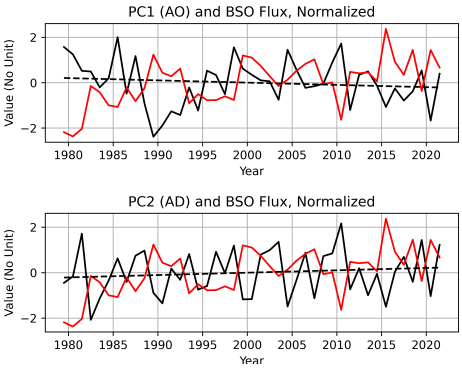




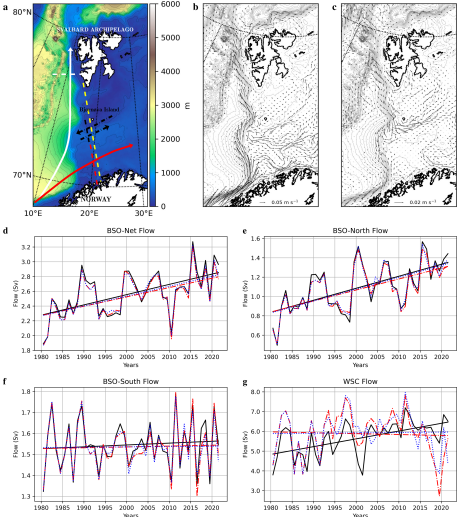
- But the Arctic Dipole trend goes in the wrong direction, and is obviously anti-correlated with the BSO flow
- So we conclude that the trend in Arctic Dipole can not explain the BSO flow trend



- But the Arctic Dipole trend goes in the wrong direction, and is obviously anti-correlated with the BSO flow
- So we conclude that the trend in Arctic Dipole can not explain the BSO flow trend
- On the contrary of what is published in Polyakov et al. 2023 (Science)



- But the Arctic Dipole trend goes in the wrong direction, and is obviously anti-correlated with the BSO flow
- So we conclude that the trend in Arctic Dipole can not explain the BSO flow trend
- On the contrary of what is published in Polyakov et al. 2023 (Science)
- The only thing we managed with our EOF analysis is to contradict a Science paper...


a
80°N
70°N
10°E
20°E
30°E
SVALBARD ARCHIPELAGO
Bjørnøya Island
NORWAY
6000
5000
4000
3000
2000
1000
0
E
b
0.05 m s⁻¹
c
0.02 m s⁻¹
d
BSO-Net Flow
Flow (Sv)
Years
e
BSO-North Flow
Flow (Sv)
Years
f
BSO-South Flow
Flow (Sv)
Years
g
WSC Flow
Flow (Sv)
Years

- All the details of the DL exercise and of our non-findings are in Jahanmard et al., JGR-Oceans 2024JC021663

- All the details of the DL exercise and of our non-findings are in Jahanmard et al., JGR-Oceans 2024JC021663
- But wait... the DL stuff said that the trend is somewhere in the wind forcing signal over the Nordic Seas non ?

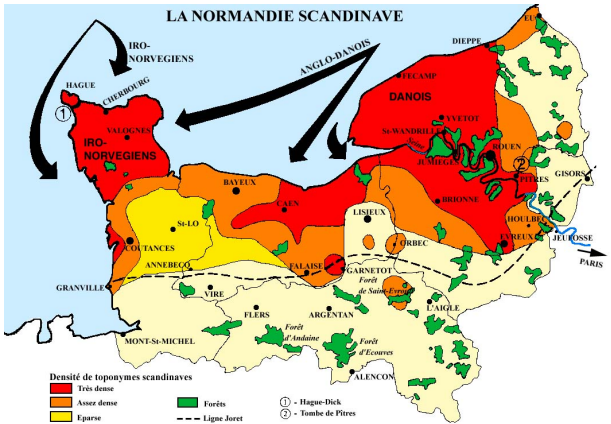
- All the details of the DL exercise and of our non-findings are in Jahanmard et al., JGR-Oceans 2024JC021663
- But wait... the DL stuff said that the trend is somewhere in the wind forcing signal over the Nordic Seas non ?
- So it is in the wind, but it is not in the wind ?? This is spooky...

- The DL nailed something we did not...

- The DL nailed something we did not...
- ... and the trend is linked with a high frequency process since hourly data is needed

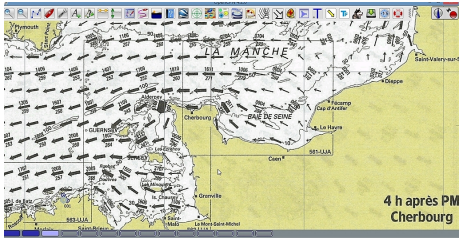
- The DL nailed something we did not...
- ... and the trend is linked with a high frequency process since hourly data is needed
- The BSO flow trend is driven by something that has a mean value of zero if one considers time periods long enough (i.e.: 3 weeks)

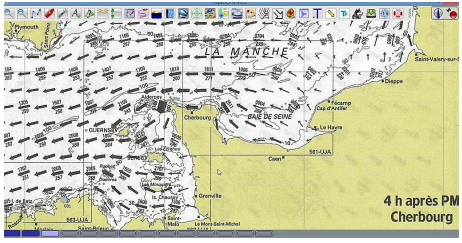
- The DL nailed something we did not...
- ... and the trend is linked with a high frequency process since hourly data is needed
- The BSO flow trend is driven by something that has a mean value of zero if one considers time periods long enough (i.e.: 3 weeks)
- This is a weak signal, the DL struggled to nail it, the training period is very long



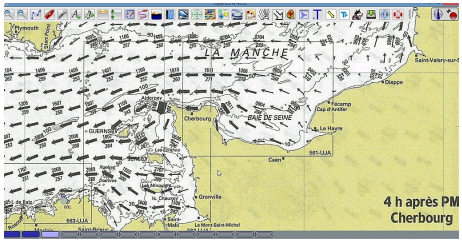
- This started to sound like something I had heard before...

- Waves can create mean currents

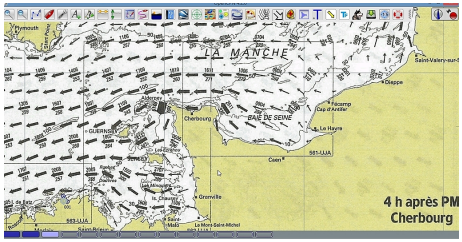




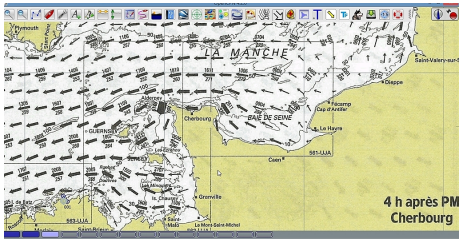
- Waves can create mean currents
- Over a wave cycle, the mean wave SSH is zero



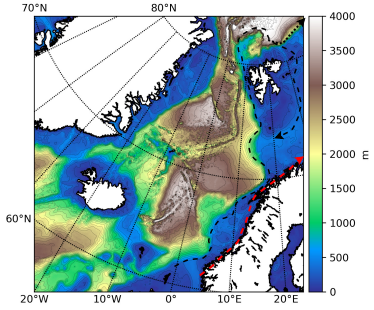
- Waves can create mean currents
- Over a wave cycle, the mean wave SSH is zero
- But the mean current created by the wave is NOT zero, there is a residual circulation



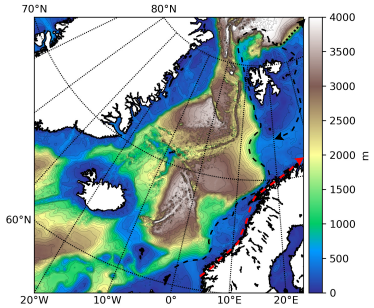
- Waves can create mean currents
- Over a wave cycle, the mean wave SSH is zero
- But the mean current created by the wave is NOT zero, there is a residual circulation
- It is a a high frequency process that creates low frequency currents



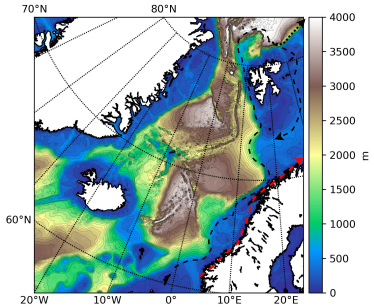
- Waves can create mean currents
- Over a wave cycle, the mean wave SSH is zero
- But the mean current created by the wave is NOT zero, there is a residual circulation
- It is a a high frequency process that creates low frequency currents
- And the behaviour of these waves/currents along the coast is highly dependent on the wave frequency



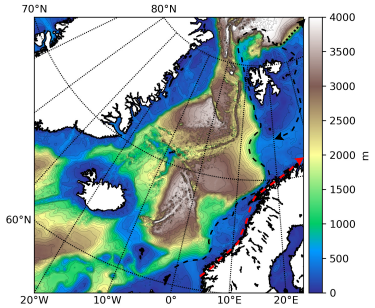
- The Norwegian coast, with its small shelf, and steep topography acts as a waveguide...



- The Norwegian coast, with its small shelf, and steep topography acts as a waveguide...
- ... which dispersive behaviour is fully documented by oceanographers thanks to tidal waves



- The Norwegian coast, with its small shelf, and steep topography acts as a waveguide...
- ... which dispersive behaviour is fully documented by oceanographers thanks to tidal waves
- Our simulations have no tides, but waves can be generated along the coast, regardless of their energy origin



- The Norwegian coast, with its small shelf, and steep topography acts as a waveguide...
- ... which dispersive behaviour is fully documented by oceanographers thanks to tidal waves
- Our simulations have no tides, but waves can be generated along the coast, regardless of their energy origin
- What if the Barents Sea Opening flow trend was caused by a change in wave driven residual circulation ?

Outline

Analysis of a Nemo-NAA10km simulation

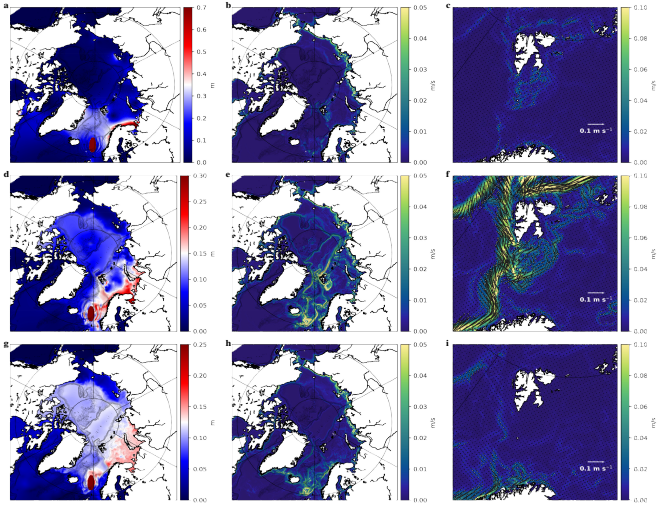
The Barents Sea Opening Flux reproduced by AI (First Version)

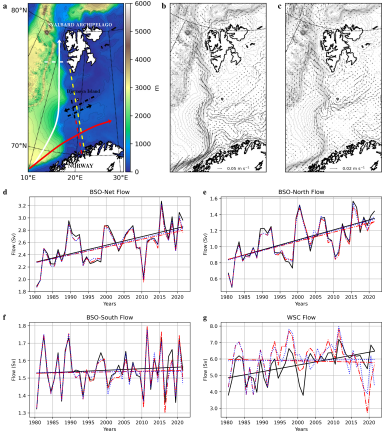
Influence of (Linear) Trends

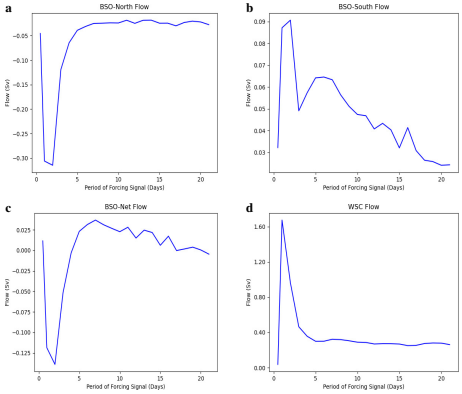
A Bouncing Experiment

Signal Processing and AI reconstruction (Second Version)

Conclusion


a
b
c
d
e
f
g
h
i
E
m/s
0.1 m s⁻¹
T=12h
T=2 days
T=7 days


a
80°N
70°N
10°E
20°E
30°E
SVALBARD ARCHIPELAGO
NORWAY
6000
5000
4000
3000
2000
1000
0
m
b
c
d
BSO-Net Flow
Flow (Sv)
Years
e
BSO-North Flow
f
BSO-South Flow
g
WSC Flow
Flow (Sv)


a
BSO-North Flow
Flow (Sv)
Period of Forcing Signal (Days)
b
BSO-South Flow
c
BSO-Net Flow
d
WSC Flow

Outline

Analysis of a Nemo-NAA10km simulation

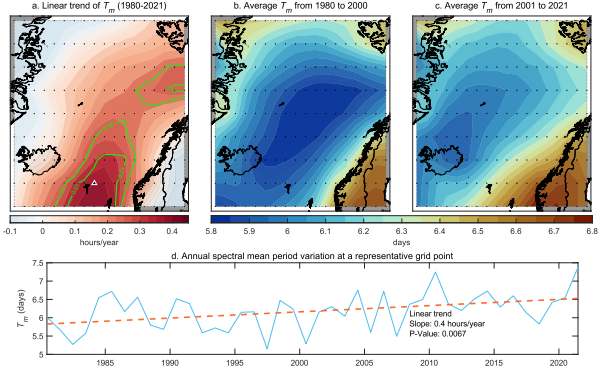
The Barents Sea Opening Flux reproduced by AI (First Version)

Influence of (Linear) Trends

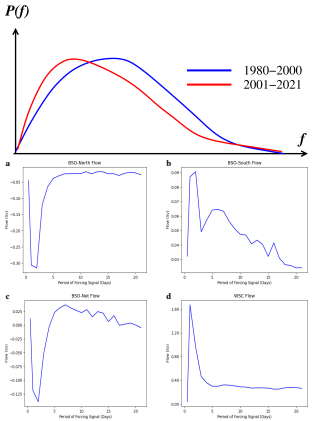
A Bouncing Experiment

Signal Processing and AI reconstruction (Second Version)

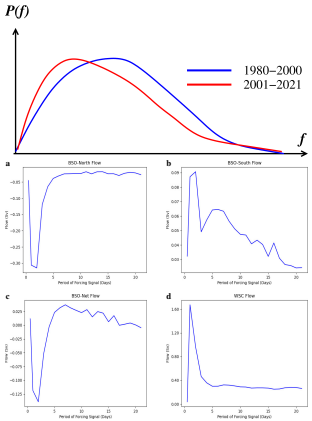
Conclusion



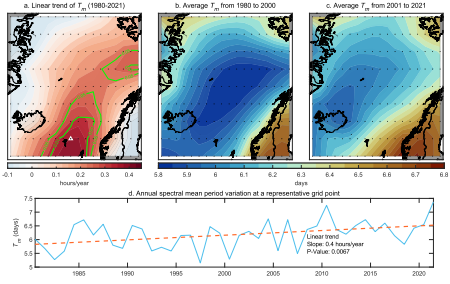
- There is indeed an increase of the synoptic time scale over the Nordic Seas



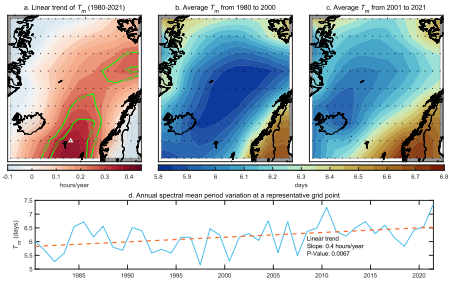
- The increase of synoptic time scale is consistent with the change of BSO flow



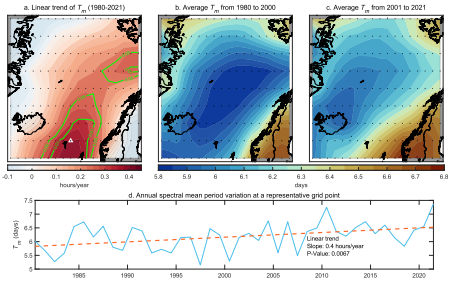
- The increase of synoptic time scale is consistent with the change of BSO flow
- We can create composite flows based on the PSD, and on the bouncing experiment, and show that shifts observed in PSD create an increase of flow at Barents Sea Opening. But is this is not quantitavely consistent.



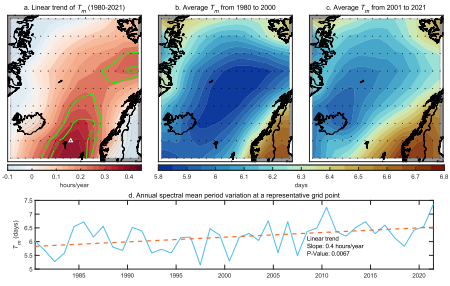
- To really nail it, we need a Nemo-NAA10km sensitivity experiment to changes in SLP/wind spectrum...



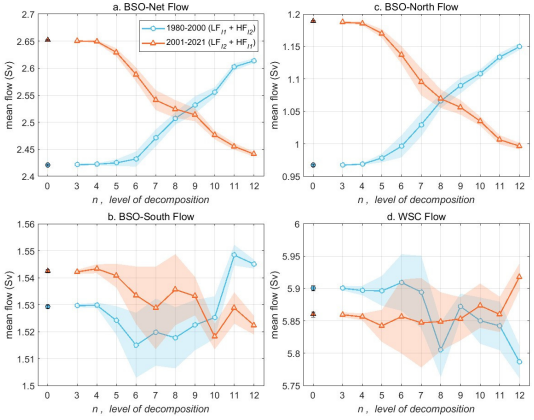
- To really nail it, we need a Nemo-NAA10km sensitivity experiment to changes in SLP/wind spectrum...
- ... which means we would need to design an atmospheric forcing in which the SLP and wind spectrum is shifted



- To really nail it, we need a Nemo-NAA10km sensitivity experiment to changes in SLP/wind spectrum...
- ... which means we would need to design an atmospheric forcing in which the SLP and wind spectrum is shifted
- But what if we could do a sensitivity experiment on something that behaves exactly like Nemo-NAA10km only on the point we are interested in, and for which changing the SLP/wind spectrum is easy ?



- To really nail it, we need a Nemo-NAA10km sensitivity experiment to changes in SLP/wind spectrum...
- ... which means we would need to design an atmospheric forcing in which the SLP and wind spectrum is shifted
- But what if we could do a sensitivity experiment on something that behaves exactly like Nemo-NAA10km only on the point we are interested in, and for which changing the SLP/wind spectrum is easy ?
- AI comes back again...



n, level of decomposition	1	2	3	4	5	6	7	8	9	10	11	12
Upper Period of Exchange (in days)	0.16	0.33	0.66	1.33	2.66	5.33	10.66	21.33	42.66	85.33	170.66	341.33

Outline

Analysis of a Nemo-NAA10km simulation

The Barents Sea Opening Flux reproduced by AI (First Version)

Influence of (Linear) Trends

A Bouncing Experiment

Signal Processing and AI reconstruction (Second Version)

Conclusion

- Our evidence shows that the trend of BSO flow is created by a change in wave propagation at the Norwegian shelf break

- Our evidence shows that the trend of BSO flow is created by a change in wave propagation at the Norwegian shelf break
- This change is created by a shift in atmospheric spectrum towards lower frequencies, the synoptic time scale over the Nordic Seas becomes longer

- Our evidence shows that the trend of BSO flow is created by a change in wave propagation at the Norwegian shelf break
- This change is created by a shift in atmospheric spectrum towards lower frequencies, the synoptic time scale over the Nordic Seas becomes longer
- Using DL permitted to find what drives the trend, using hints given by trial & error process to reconstruct the signal, and a process of elimination

- Our evidence shows that the trend of BSO flow is created by a change in wave propagation at the Norwegian shelf break
- This change is created by a shift in atmospheric spectrum towards lower frequencies, the synoptic time scale over the Nordic Seas becomes longer
- Using DL permitted to find what drives the trend, using hints given by trial & error process to reconstruct the signal, and a process of elimination
- Using DL also allowed building a spectral surrogate model, based on results of a non-spectral model

- Our evidence shows that the trend of BSO flow is created by a change in wave propagation at the Norwegian shelf break
- This change is created by a shift in atmospheric spectrum towards lower frequencies, the synoptic time scale over the Nordic Seas becomes longer
- Using DL permitted to find what drives the trend, using hints given by trial & error process to reconstruct the signal, and a process of elimination
- Using DL also allowed building a spectral surrogate model, based on results of a non-spectral model
- Now published in Nature CC.