Biophysical frequency response of the Bering Sea to large-scale forcing

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FOCUS

• This session theme is focused on predictability of large-scale climate
• Predictability is strongly dependent on space and time scales.
• Here, consider “predictability” of small (~100km square) regions if had perfect knowledge of some forcing variable there – look for coherence across frequency bands
• Consider physical and biological variables
BEST/BSIERP Integrated Modeling

Higher trophic levels
(Pollock etc.)

Secondary Producers
(Zooplankton)

Primary Producers
(Phytoplankton)

Nutrients
$\text{NO}_3$, $\text{NH}_4$...

Physical Forcing
(Wind, temp, sun)

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Economic/ecological model

FEAST Higher trophic level model

NPZ
Lower trophic level ecosystem model

ROMS
Physical oceanography

Climate scenarios
10 layers, 10-km grid
Includes ice and tides
CCSM heat flux algorithms
Physical model vs. data
BEST/BSIERP modeling results: cold pool, phytoplankton and velocity
Close-up of Southern Shelf
Overview of method

• For each bioregion: calculate time series of deviations from the seasonal climatology for major forcing variables and significant modeled attributes of the ocean ecosystem

• Look for pairwise coherence among these deviations
  – Physical: Tocn, Tair, swrad, lwrad, wind stress
  – Biological: euphausiid biomass

• Notes and cautions:
  – coherence analysis is similar to lagged correlations of band-passed signals
  – there is coherence among the forcing variables themselves, and among the ocean attributes themselves. Hence an established coherence may not reflect a simple forcing relationship (but still useful for prediction)
  – nonlinear relationships may confound simple linear coherence
Model Forcing Variables

- Wind Velocities
- Air Temperature
- Air Specific Humidity
- Sea Level Pressure
- Rainfall
- Runoff
- Downwelling Shortwave
- Downwelling Longwave
Major terms in the outer shelf seasonal heat budget (W m$^{-2}$, positive = into the ocean)

swrad is BIG
Expected frequency response 1: thermal inertia reddens the input spectrum

\[
\frac{dT}{dt} = \frac{(F - \lambda^*T)}{H}
\]

\[
F \sim F_0 e^{i\omega t}, T \sim T_0 e^{i\omega t}
\]

\[
\frac{T_0}{F_0} \sim \frac{1}{(Hi\omega + \lambda)}
\]

as \(\omega \to 0\), \(\frac{T_0}{F_0} \to 1/\lambda\)

as \(\omega \to \text{huge}\), \(\frac{T_0}{F_0} \to 0\)

white \(F \to \) red \(T\)

red \(F \to \) redder \(T\)

\(T = \) ocean temperature

\(H = \) ocean depth

\(F = \) surface heat forcing

\(\lambda = \) rate of heat loss at surface (e.g. sensible, longwave)

\(\omega = \) frequency
Expected frequency response 2: Biological reddening and resonance

• Some biological terms will simply redden the spectrum of the physical forcing (as with heat example, simple integration does this)

• HOWEVER, if physical forcing matches a fundamental period of the biology, can get “resonance”
  – Example: recurrence period of favorable conditions corresponds to time lag between birth and reproduction
Physical Results

• Four forcing datasets were used:
  • Hindcast
  • IPCC forecast
    – MIROC (2003-2040)
    – CCCMA (2003-2040)
    – ECHO-G (2004-2040)
CORE forcing: Mid-shelf $T_{ocn}$ is positively coherent with $T_{air}$ on annual to decadal scales

- red, green, blue lines indicate 90%, 95%, 99% confidence levels for coherence significantly different than zero
- positive phase means top variable leads bottom variable
CORE forcing: Inner-shelf $T_{ocn}$ is positively coherent with along-shelf wind stress on annual to interdecadal timescales.

Note how windstress has *whiter spectrum* than air temperature.
CORE forcing: Mid-shelf $T_{ocn}$ is positively coherent with along-shelf wind stress on annual to interdecadal timescales.
CORE forcing: Outer-shelf $T_{ocn}$ is NOT coherent with along-shelf wind stress on longer timescales
CORE forcing: Mid-shelf $T_{ocm}$ is NOT coherent with swrad

- **swrad anomalies bioregion 3**
  - X: 0.5 to 40.5
  - DATA SET: coher-core

- **swrad bioregion 3 spectra**
  - X: 0.5 to 40.5
  - DATA SET: coher-core

- **coherence**
  - X: 0.5 to 40.5
  - DATA SET: coher-core

- **temp_100m anomalies bioregion 3**
  - X: 0.5 to 40.5
  - DATA SET: coher-core

- **temp_100m bioregion 3 spectra**
  - X: 0.5 to 40.5
  - DATA SET: coher-core

- **phase lag**
  - X: 0.5 to 40.5
  - DATA SET: coher-core
CORE forcing:
swrad (x-axis) vs Tocn (y-axis)
## Summer Cloudiness (from Bond 2012)

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<th>Year</th>
<th>Western Bering</th>
<th>Eastern Bering</th>
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<td>0.88</td>
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<tr>
<td>2008</td>
<td>0.76</td>
<td>0.85</td>
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</tbody>
</table>
CORE forcing: Mid-shelf $T_{ocn}$ is positively coherent with lwrad at annual to decadal scales
Biological Results

• Models and data have suggested inverse correlation between ocean temperature and large crustacean zooplankton
• Does this hold across all frequency bands?
CORE forcing: Outer-shelf euphausiids are *negatively* coherent with $T_{ocn}$ at annual and decadal scales.

Note how euphausiids have whiter spectrum than physical ocean variables.
CORE forcing: Mid-shelf euphausiids are *negatively* coherent with Tocn at annual and decadal scales.
CORE forcing: Inner-shelf euphausiids are coherent with $T_{ocn}$ at annual scales
CORE forcing: Northern shelf euphausiids are positively coherent with Tocn across most frequencies.
Do these relationships hold for the IPCC forcing runs?

• Generally yes, with some interesting differences....
MIROC forcing: Mid-shelf $T_{\text{ocn}}$ is \textit{negatively} coherent with swrad at annual to decadal scales.
MIROC forcing: Mid-shelf $T_{ocn}$ is positively coherent with $lwrad$ at annual to decadal scales
MIROC forcing: Mid-shelf $T_{ocn}$ is positively coherent with along-shelf wind stress on interannual to interdecadal timescales
CCCMA forcing: Mid-shelf $T_{ocn}$ is positively coherent with $lwrad$ at interannual to decadal scales
CCCMA forcing: Mid-shelf $T_{ocn}$ is coherent with along-shelf wind stress on interannual timescales.
Summary

- Tocn IS coherent with TaIR, esp on longer time scales
- Tocn IS coherent with alongshelf wind-stress
- Tocn IS NOT coherent with shortwave input, but IS coherent with longwave input
- Euphausiid biomass IS coherent with with Tocn, esp on longer time scales. Out of phase at long time scales, in-phase on short time scales at some locations
Interpretation

• Coherence with winds, air temperature and longwave suggest these are the better predictors of heat content than shortwave!

• Coherence of euphausiids with ocean temperature may be useful for inferences regarding fish (e.g. the Oscillating Control Hypothesis of Hunt et al. 2012)