ES 520 Midterm Exam Review Sheet

Format (100 points total):
T/F, fill in the blank & multiple choice (~50 points, closed notes)
Short answer (~50 points, open notes)

Readings:
You should be familiar with the concepts and main take-away points from the papers / in-class discussions pertaining to each of the modes we have discussed so far.
Approximately ~1/2-2/3 of the exam will cover the new material since exam 2, and remaining ~1/3-1/2 overarching questions that synthesize material throughout the semester.

1. Annular modes: Abram et al. 2014, Barnes et al. 2013
2. Atlantic Multidecadal Oscillation: Henry et al. 2016, Brown-Galbraith et al. 2016
3. Pacific Decadal Oscillation: Di Lorenzo et al. 2015, Liguori et al. 2018; Newman et al. 2016; DeLong et al. 2012, England et al. 2014
4. Future Modes: Klower et al. 2014, Chylek et al. 2016

Topics:

Overarching concepts (direct from midterm review sheet):
- What are the dominant processes that control mean climate on earth?
- What is climate? How is a site's climatology calculated? What is an anomaly with respect to the mean climate of a site/ region?
- Broadly speaking, how does climate vary zonally and meridionally across the earth's surface? What drives symmetries and asymmetries in these patterns?
- What causes seasonal variability in climate? How was seasonality different during the mid-Holocene (and why?)?
- What is the ultimate driver of atmospheric and oceanic circulation in the earth system?
- What controls the horizontal movement of air (i.e. wind)? How are these wind patterns impacted by coriolis effect (in each hemisphere)? How does coriolis effect vary with latitude?
- Where are the global wind belts, areas of convection / convergence, and areas of descending air / divergence? How do these patterns relate to mean climate conditions?
- How does vorticity relate to areas of cyclogenesis? What factors produce vorticity?
- What are the factors that control ocean circulation patterns? Surface current patterns? Deep ocean circulation patterns?
- What is the net direction of surface current transport, relative to that of the surface wind direction?

- What processes drive (wind-driven) upwelling and downwelling? What are some examples of where these processes occur? How does this relate to marine productivity?
- What factors control variations in salinity across the global oceans?
- What factor(s) drive the thermohaline (overturning deep-water) circulation? What are the major areas of deep-water formation? Is the thermohaline circulation slowing in response to climate change?
- What is the difference between historical observational products and reanalyses? What data and/or models go into each, and how are the ultimate products you download obtained (i.e. what happens "behind the scenes" to the data)?
- What pre-processing is applied to our historical "observations" and why are they needed? What are some examples of bias corrections that are necessary for historical climate data?
- What is model resolution, why is it important for simulating our climate system, and what are some of the potential costs of higher resolution?
- What is model parameterization, and how does it relate to model resolution?
- What is a model ensemble? What are the types of model ensembles, and what type of uncertainty is each typically used to test?
- How can we model the climate at the end of the century, when we cannot predict the weather 2 weeks from now?
- What is red noise, and how does it relate to the autocorrelation structure of a time series? What are some processes or components of the climate system that are characterized by red noise? Why?
- What are the implications of red noise for interpreting climate signals?
- What is the signal to noise ratio of a time series (with respect to some climate process/ mode of interest), and why is it important for detection and attribution studies? How does this relate to the size of the ensemble used for detection/ attribution?
- What is covariance and how does covariance vary by distance in the climate system? What does this mean?
- Why is EOF analysis a powerful tool for identifying modes of climate variability? What is one major limitation of this analysis? What do the EOF loadings ("eigenvectors"), principal components ("PCs"), and eigenvalues ("λ") tell us about each mode?
- As our climate system continues to warm, will we see changes to the:
  - ***background state*** of the tropical Pacific?
  - ***frequency*** of ENSO events?
  - ***spatial pattern*** of ENSO events?
  - ***intensity*** of ENSO events?

  Be familiar with various proposed hypotheses, and the current balance of evidence for each.
- What are some challenges to the detection and attribution of changes in ENSO with warming?
- What are paleoclimate archives and how can we used them to study modes of climate variability in the past? What are some of their strengths and limitations?

- How is the Indian Ocean mean state and variability (i.e. strength, frequency of IOD events) expected to change in the future (based on our current understanding)?

New concepts:

- What is an annular mode?
- How is the Southern Annular Mode defined? Describe the temperature (ocean and air), sea-level pressure, precipitation, and wind patterns associated with a positive (negative) phase of the SAM. How/ why does the SAM impact Ekman upwelling and sea-ice patterns?
- How are SAM and ENSO related? What is the impact of ENSO on Antarctic / Southern Ocean climate?
- Describe recent trends in the SAM, and how these trends relate to greenhouse gas and ozone forcing (i.e. what is the proposed mechanism by which these forcings impact SAM).
- How are the North Atlantic Osciallation and Northern Annular Mode defined, and how are these modes related?
- Describe the temperature (ocean and air), sea-level pressure, precipitation, and wind patterns associated with a positive (negative) phase of the NAM. How are extreme winter weather events related to the NAM (and which phase has greater occurrences of extreme events)?
- Describe recent trends in the NAM, and how these trends relate to greenhouse gas and ozone forcing (i.e. what is the proposed mechanism by which these forcings impact NAM). Do these trends differ between the Atlantic and Pacific basins, and if so, how?
- How has the vertical temperature profile of the atmosphere changed with greenhouse gas forcing? " " ozone forcing?
- What is the Atlantic Multidecadal Oscillation? How is it defined? What is the timescale of this mode of variability?
- What are the challenge(s) with defining the AMO, and what approach(es) have been used to address these?
- Describe the two proposed links between the AMO and AMOC discussed in class (i.e. via heat flux vs freshwater flux). How long do these processes take, and are they consistent with the timescale of the AMO?
- What is the current state and trend of the AMO, and what do models project for the near-term future?
- Describe how the "bipolar seesaw" relates to AMOC variability and abrupt climate changes. What likely caused these abrupt climate events observed over past glacial-interglacial cycles? What paleo evidence do we have for this?
- Based on the model simulations, is it conceivable to get abrupt changes in the absence of freshwater forcing? Does the background climate state matter (e.g. glacial vs modern climate state)? What are the implications for future AMO / climate?
- How is the Pacific Decadal Oscillation defined? How does it relate to SLP variability over the North Pacific / Pacific North American Pattern?
- What is the Interdecadal Pacific Oscillation, and how is it defined?

- What are some of the global teleconnections of the PDO/IPO, and what impact may it have on global air temperature warming (i.e. why are near-term predictions of the PDO/ IPO so important)? What is the proposed link between PDO/IPO/PDV and global warming? What is the evidence for this?
- What are some of the proposed mechanisms for generating decadal variability in the Pacific? What role do the tropics play in PDV?
- What are some of the challenges with reconstructing Pacific Decadal Variability?
- How well do models simulate the PDV? How much does internal variability contribute to the discrepancies among models?
- What mode(s) of variability modulate precipitation over the continental US?
- To what degree do initial value and forced boundary condition uncertainties impact decadal prediction? In the current state-of-the-art GCMs, how well can we predict climate over the next 5-10 years? How does this compare to our ability to predict near-term climate using memory alone?
- What is a wavelet spectrum, and why is it a useful tool for studying modes of climate variability (i.e. what does it allow us to see that we can't with other methods)? " " wavelet coherence?

Synthesis:
Describe the process you'd take to answer the following questions about a climate variable over a region of interest (e.g. winter precipitation over New England):

1. What modes of climate variability influence this variable? How certain are we?
2. How are these modes expected to change? How certain are we?
3. What are some of the uncertainties we need to consider?
4. To what degree of certainty can we predict forced changes? Over the next 5-10 years? 100 years? Why does our confidence in these projections differ, if at all? Why?

Terms to know:
Climate / climate system
Climatology
Climate anomaly
Albedo
Zonal
Meridional
Pressure gradient force
Coriolis effect
Intertropical convergence zone (ITCZ)
Sub-tropical jet
Mid-latitude/ polar jet
Vorticity
Potential vs absolute vorticity
Rossby or planetary waves
Ekman transport
Upwelling / downwelling
Wind drag
Thermocline / halocline / pycnocline
Thermohaline circulation
Historical data
Data assimilation
Reanalysis
Model resolution
Parameterization
Large ensemble / Initial condition ensemble
Perturbed physics ensemble
Multimodel ensemble
Initial condition uncertainty
Forecast uncertainty
Model uncertainty
Prediction vs Projection
Initial value problem

Boundary value problem
Emissions scenarios
Representative concentration pathways
Detection vs attribution
Red vs white vs blue spectra
Emperical
Orthogonal
Emperical Orthogonal Function
Modes of variability
Covariance
Weaker walker
Ocean thermostat
Teleconnection
Heat capacity
Mid- Holocene Optimum
Eccentricity
Obliquity
Precession
Paleoclimate archives
Length vs temporal resolution
$\delta^{18}O$
Annular
Northern Annular Mode
Southern Annular Mode
Antarctic Oscillation
Stochastic process
Stationary vs non-stationary
Spectral analysis

North Atlantic Oscillation
Ozone
Atlantic Meridional Overturning
Circulation
Heinrich event
Bond cycle
P/Th
Conservative vs Scavenged elements
PNA
IPO
PDO
NPGO
PDV
Reemergence mechanism
Decadal prediction
Meridional Mode
Hiatus
Ocean heat content
SHPDO
SPCZ
Wavelet spectra