ES 520 Midterm Exam Review Sheet

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

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.

1. Intro to climate dynamics: Ruddiman Ch 2, Kohli Ch 3, Pinet Ch 6;
2. Climate data/reanalysis/ modeling: Deser et al. 2010, Dee et al. 2014, Weart 2008;
3. Timescales of variability: Wunch 1999, Deser et al. 2012
4. ENSO: Cai et al. 2014, Yeh et al. 2009, Vecchi et al. 2010; Dai et al. 2000, Li et al. 2015
5. Monsoons: Thompson et al. 2000, Staubwasser et al. 2003
6. IOD: Saji and Yamagata 2003, Ashok et al. 2004

Equations:
You should be broadly familiar with the following equations and understand how they relate to processes we have discussed in class. **[I don't expect you to memorize these, only know their importance in the context of overarching concepts / questions from class (see "Topics" below).]**

- $CE = 2\Omega(\sin\Phi)v$
- $F = \sigma T^4$
- $\lambda_{max} = \frac{3000\ \mu m}{T(K)}$
- $S = S_o (r_o/r)^2$
- $PV = nRT$
- $\rho = m/V$
- Vorticity:
    - Absolute vorticity = relative vorticity + planetary (or earth/coriolis) vorticity
    - Absolute vorticity = shear + curvature + f (coriolis)
    - Absolute vorticity/Δ height = constant
- $|\tau| = Cd\ \rho_a U^2$
- $P = \rho g h$
- $R = F^T F$ *or* $R = [(x - xmean)^T * (y - ymean)]/ nt-1$

Topics:

- 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?
- How does the amount of incoming and outgoing solar radiation vary with respect to latitude, and what are the main drivers of this pattern?

- How does albedo vary across the earth's surface? What surfaces have high (low) albedo? How does albedo relate to cloud type?
- 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 are geostrophic balance and western boundary intensification, and how do they relate to gyre circulation? How do western boundary currents compare to eastern boundary currents (speed, depth, temperature)? Why are gyres asymmetric?
- 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?
- How do Bjerknes feedbacks between the ocean and atmosphere act to reinforce conditions in the tropical Pacific?
- Although mechanisms for phase transitions among ENSO states are still not fully understood, what are two key conditions needed for the development of an El Niño event?
- How does ENSO influence precipitation patterns globally (i.e. what are a few major ENSO teleconnections)? Why?
- What are the different "flavors" of ENSO diversity (i.e. types of ENSO events)? Do teleconnections differ between these two types of ENSO events (e.g., precipitation over North America)? If so, why?
- 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?
- How are monsoon regions defined, and what are the dominant process(es) driving monsoon variability?
- What are the major regions of the "Asian Monsoon System", how have they been identified, and what are the major similarities and differences among them?
- What are the two "modes" of the "global monsoon system"? What ultimately drives monsoons globally?
- What is the relationship between ENSO and the Indian Summer Monsoon / Asian Monsoon system? Is this relationship expected to change with warming / climate change? If so, how and why?
- How well do climate models simulate monsoon systems? How does this performance compare between individual models and the multi-model ensemble? What are some of the major challenges to modeling the monsoon(s)?
- Compare and contrast interannual variability in the tropical Pacific and Indian Oceans. How are they similar, yet different, in terms of their patterns of variability and driving mechanisms?

- How do monsoon winds, trade winds and ocean temperatures in the Indian Ocean interact in the initiation, maintenance and decay of IOD events (hint: how do the Bjerknes, wind-evaporation, and SST-cloud-radiation feedbacks play a role in the IOD?)?
- Are IOD and ENSO independent modes? Does their relationship (and their relationship with the monsoons) vary through time?
- 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?
- Did the strength of the monsoon(s), ENSO, and IOD change during the mid-Holocene? If so, what was likely responsible for these changes?
- 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)?

Synthesis questions:

Terms to know:

Climate / climate system
Climatology
Climate anomaly
Blackbody radiation
Flux
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
Geostrophic flow
Gyres
Westward intensification
Upwelling / downwelling
Wind drag
Thermocline / halocline / pycnocline
Thermohaline circulation
Red vs white vs blue spectra
Emperical
Orthogonal
Emperical Orthogonal Function
Modes of variability
Covariance
Historical data
Bias correction
Interpolation
Data assimilation
Reanalysis
Model resolution
Parameterization
Flux correction
Model spin up
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
Stochastic process
Stationary vs non-stationary
Spectral analysis
Walker circulation
Southern Oscillation
ENSO
Bjerknes feedback
Normal vs. El Niño vs La Niña
Weaker walker

Clausius- clapeyron
Ocean thermostat
Teleconnection
Monsoon(s)
Heat capacity
Continentality
Asian monsoon “system”
Indian Summer monsoon / South Asian monsoon
East Asian monsoon
Western North Pacific monsoon
West African Monsoon
Indian Ocean Dipole
Mid- Holocene Optimum
Eccentricity
Obliquity
Precession
Paleoclimate archives
Length vs temporal resolution
$\delta^{18}O$