SIOC 221A Homework 9 **Julia Dohner**
Prof. Sarah Gille Due Date: December 13, 2017

1. Spectra.

For this project, I chose to analyze the atmospheric CO2 records measured at the La Jolla, Mauna Loa, and South Pole stations as part of the Scripps CO2 Program. I started by trying to analyze the daily records, but because there were too many gaps in the daily record taken in La Jolla, I switched to looking at the monthly records.

I computed the spectra by splitting my data into 8 non-overlapping segments with Hanning windows applied. The spectra show a peak at 1 cycle per year for the annual cycle, as well as a peak at 2 cycles per year, likely the harmonic of the annual cycle. In both the time series plot and the spectra the dampening of the annual cycle in the South Pole record can be clearly seen. The South Pole is much less influenced by a seasonal cycle because of the lack of biomass in the Southern Hemisphere (fewer trees and other plants flourishing in the summer to draw down CO2). We can also see that the South Pole data shows opposite phasing than the records from the Northern Hemisphere because the seasons are reversed in the Southern Hemisphere.

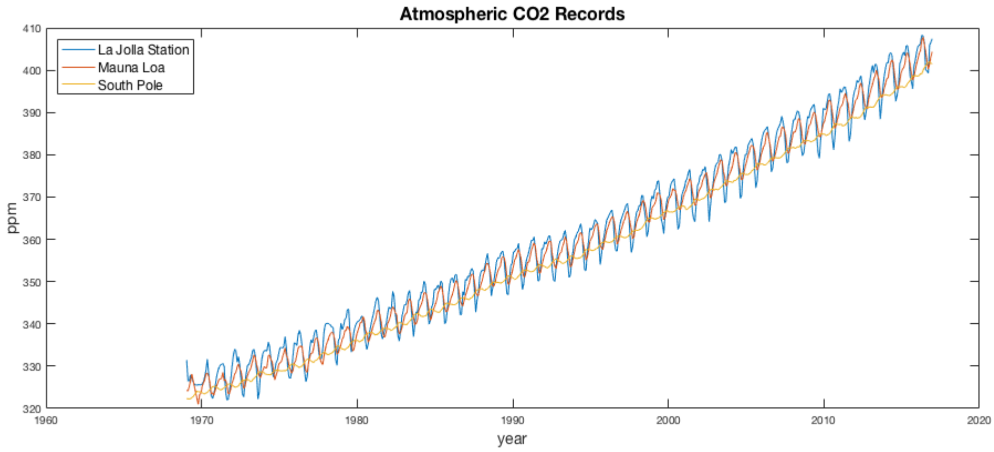
2. Coherence.

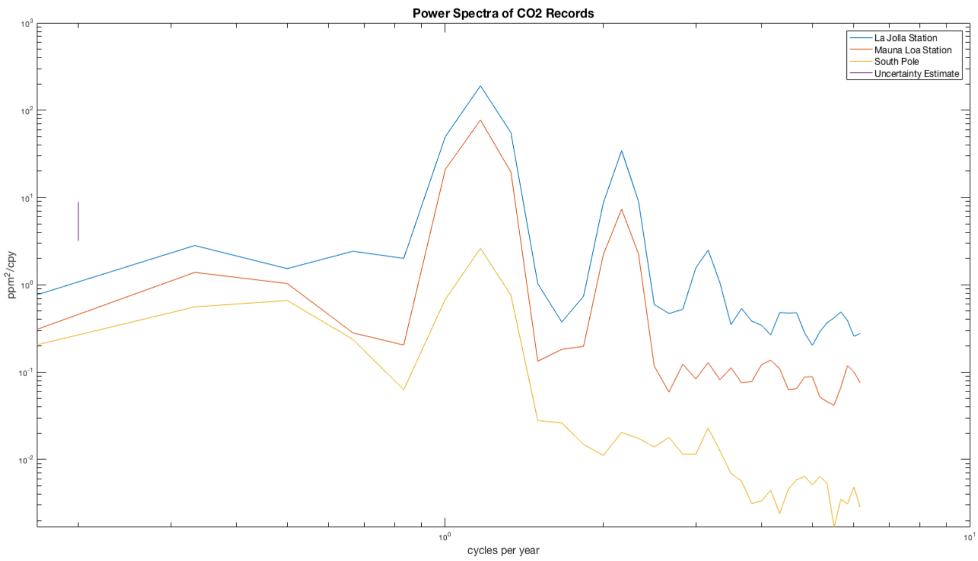
The Mauna Loa and La Jolla records, as well as the Mauna Loa and South Pole records, appear to be statistically coherent at one and two cycles per year, as expected due to the imprint of the annual cycle on both detrended records. The phase diagrams reveal that the Mauna Loa and La Jolla records are in phase (phase difference of 0 at low frequencies), whereas the Mauna Loa and South Pole records are oppositely phased (phase difference of nearly negative pi at low frequencies), with the South Pole lagging Mauna Loa. The opposite phasing is to be expected as the seasons in the Northern and Southern Hemispheres are opposite.

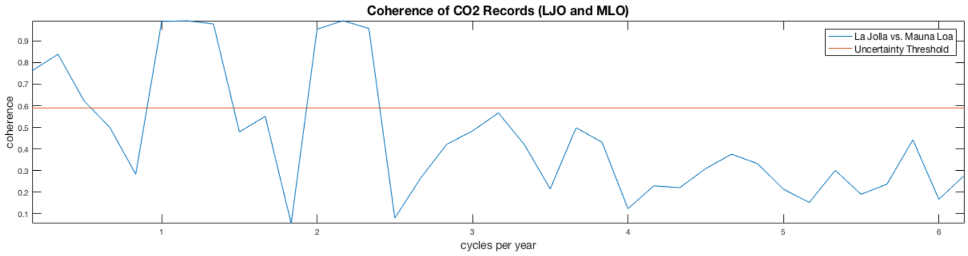
2. Additional notes.

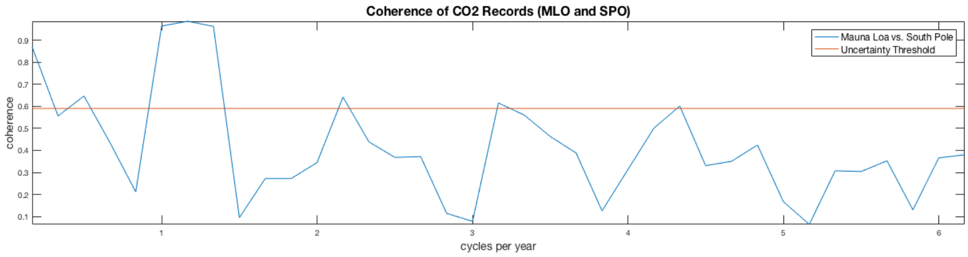
I was interested in analyzing 10-minute and daily CO2 records in addition to the monthly timeseries to see if I could resolve a daily cycle in the 10-minute record and more clearly resolve the phasing differences between data taken in the Northern Hemisphere and Southern Hemisphere through the daily records. Unfortunately neither the 10-minute nor daily records contained a long enough continuous stretch of measurements to complete a meaningful analysis. I did tinker with the daily record (interpolating between missing points) and produced a phase diagram that showed a clear lag between the records, but the rest of the analysis was fairly messy because of the short record, so I chose to omit it from my project. The periodogram was a disaster, but I speculate that it was because for the length of data I was using (just over one year), I wouldn't be able to resolve the annual cycle, and the measurements were too infrequent to resolve a diurnal cycle, thus I wasn't getting any well-resolved peaks.

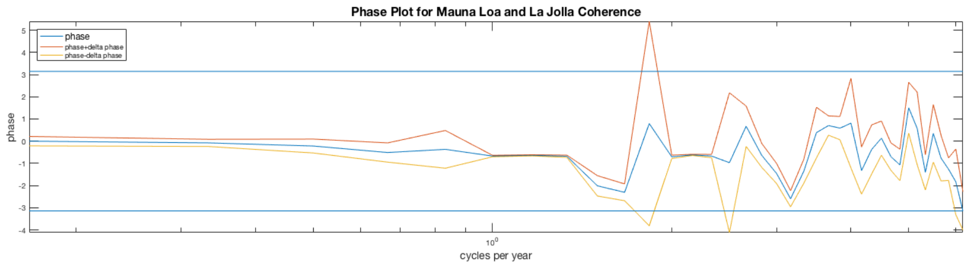
The 10-minute data would have been useful for resolving a diurnal cycle in the CO2 record, one present due to the reversal of the boundary layer and from pollution blowing in from elsewhere. Unfortunately, too many gaps existed in the data (I couldn't find a chunk of data that lasted longer than a day), so I omitted this data as well.

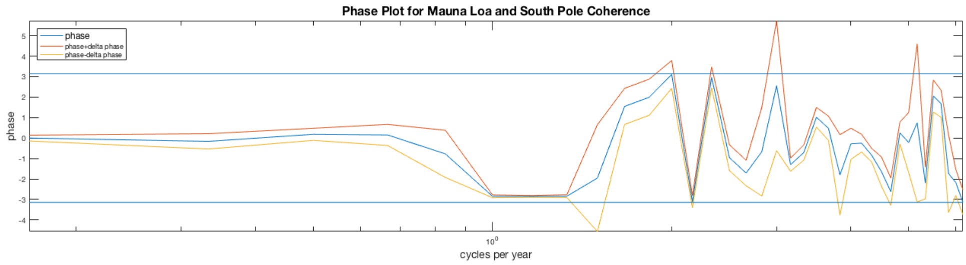





Coherence of CO2 Records (LJO and MLO)
La Jolla vs. Mauna Loa
Uncertainty Threshold
coherence
cycles per year


Coherence of CO2 Records (MLO and SPO)
Mauna Loa vs. South Pole
Uncertainty Threshold
coherence
cycles per year


Phase Plot for Mauna Loa and La Jolla Coherence
phase
phase+delta phase
phase-delta phase
phase
cycles per year


Phase Plot for Mauna Loa and South Pole Coherence
phase
phase+delta phase
phase-delta phase
phase
cycles per year

```
% file SIOC 221A HW 9 - monthly
%
% author Julia Dohner
%
% due date December 13, 2017

% analysis of monthly flask-collected co2 data at Mauna Loa, La Jolla↙
and
% the South Pole stations

clear all; close all;

%% load CO2 data

dataMLO = fopen('monthly_data/monthly_flask_co2_mlo_JLD.txt');
dataLJO = fopen('monthly_data/monthly_flask_co2_ljo_JLD.txt');
dataSPO = fopen('monthly_data/monthly_flask_co2_spo_JLD.txt');

valsMLO = textscan(dataMLO, '%f %f', ...
    'delimiter','\t');
valsLJO = textscan(dataLJO, '%f %f', ...
    'delimiter','\t');
valsSPO = textscan(dataSPO, '%f %f', ...
    'delimiter','\t');

fclose(dataMLO);
fclose(dataLJO);
fclose(dataSPO);

% format of .txt files is year, co2 value
LJOyear = valsLJO{1};
LJOco2 = valsLJO{2};

MLOyear = valsMLO{1};
MLOco2 = valsMLO{2};

SPOyear = valsSPO{1};
SPOco2 = valsSPO{2};

% remove flagged data
for i = 1:length(MLOco2)
    if MLOco2(i) == -99.99
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        MLOco2(i) = nan;
    end
end
for i = 1:length(LJOco2)
    if LJOco2(i) == -99.99
        LJOco2(i) = nan;
    end
end
for i = 1:length(SPOco2)
    if SPOco2(i) == -99.99
        SPOco2(i) = nan;
    end
end

% remove nan's
addpath↙
('/Users/juliadohner/Documents/MATLAB/SIOC_221A/HW9/Inpaint_nans/Inpa↙
int_nans');
MLOco2 = inpaint_nans(MLOco2);
LJOco2 = inpaint_nans(LJOco2);
SPOco2 = inpaint_nans(SPOco2);


%% inspect spacing of data

% inspect time spacing between measurements
MLO_t_diff = diff(MLOyear);
LJO_t_diff = diff(LJOyear);
SPO_t_diff = diff(SPOyear);

% figure
% plot(1:length(MLOyear)-1,MLO_t_diff);
% figure
% plot(1:length(LJOyear)-1,LJO_t_diff);
% figure
% plot(1:length(SPOyear)-1,SPO_t_diff);

minDiffLJO = min(LJO_t_diff);
maxDiffLJO = max(LJO_t_diff);
minDiffMLO = min(MLO_t_diff);
maxDiffMLO = max(MLO_t_diff);
minDiffSPO = min(SPO_t_diff);
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```
maxDiffSPO = max(SPO_t_diff);

% too big differences in time increments of daily LJO flask sampling,↙
will try
% monthly data instead

% update: time differences range between 0.0767 and 0.0850 years for↙
both
% MLO and LJO records (difference of 0.0083) or ~3 days, deemed small
% enough difference in time increments
% read: counts in my book as even spacing

%% shorten data to same lengths

startYear = LJOyear(1,1); % latest start
endYear = SPOyear(length(SPOyear),1); % earliest end
startIndex_LJO = find(LJOyear == startYear);
startIndex_MLO = find(MLOyear == startYear);
startIndex_SPO = find(SPOyear == startYear);
endIndex_LJO = find(LJOyear == endYear);
endIndex_MLO = find(MLOyear == endYear);
endIndex_SPO = find(SPOyear == endYear);

% create new vectors
LJOco2_2 = LJOco2(startIndex_LJO:endIndex_LJO);
LJOyear_2 = LJOyear(startIndex_LJO:endIndex_LJO);
MLOco2_2 = MLOco2(startIndex_MLO:endIndex_MLO);
MLOyear_2 = MLOyear(startIndex_MLO:endIndex_MLO);
SPOco2_2 = SPOco2(startIndex_SPO:endIndex_SPO);
SPOyear_2 = SPOyear(startIndex_SPO:endIndex_SPO);

% plot timeseries
figure('name','Atmospheric CO2 Timeseries');
plot(LJOyear_2,LJOco2_2, MLOyear_2,MLOco2_2,SPOyear_2,SPOco2_2);
xlabel('\fontsize{14}year')
ylabel('\fontsize{14}ppm')
%title('\fontsize{20}Atmospheric CO2 Records')
legend('\fontsize{18}La Jolla Station','\fontsize{18}Mauna Loa',↙
'\fontsize{18}South Pole','Location','southeast');


%% compute spectra (from in-class coherence example)
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N = length(LJOco2_2);
Nseg = 8; % number of segments splitting data into
segment_length = N/Nseg; % length of each chunk of data (aka segment↙
length)
M = segment_length/2;


% 72-long segments
LJO_use = [reshape(LJOco2_2,segment_length,Nseg)];
MLO_use=[reshape(MLOco2_2,segment_length,Nseg)];
SPO_use=[reshape(SPOco2_2,segment_length,Nseg)];

LJO_ft=fft(detrend(LJO_use).*(hann(segment_length)*ones(1,Nseg)));
MLO_ft=fft(detrend(MLO_use).*(hann(segment_length)*ones(1,Nseg)));
SPO_ft=fft(detrend(SPO_use).*(hann(segment_length)*ones(1,Nseg)));

LJO_spec=sum(abs(LJO_ft(1:M+1,:)).^2,2)/N; % sum over all spectra↙
(2nd dim)
LJO_spec(2:end)=LJO_spec(2:end)*2; % multiply by 2 to make up for↙
lost energy

MLO_spec=sum(abs(MLO_ft(1:M+1,:)).^2,2)/N;
MLO_spec(2:end)=MLO_spec(2:end)*2;

SPO_spec=sum(abs(SPO_ft(1:M+1,:)).^2,2)/N;
SPO_spec(2:end)=SPO_spec(2:end)*2;

%% uncertainty estimate on spectra

nu = 1.9*2*Nseg; % DOF = 2*number of segments*1.9 (1.9 for the↙
Hanning)
err_high = nu/chi2inv(0.05/2,nu);
err_low = nu/chi2inv(1-0.05/2,nu);
ratio_chi2 = err_high/err_low;

%% plot spectra

frequency=(1:M+1)/(segment_length/12);
frequency = frequency';

figure('name','Power Spectra of CO2 Records');
```

```
loglog(frequency,LJO_spec,  ...
    frequency, MLO_spec,  ...
    frequency, SPO_spec, [.2 .2],[err_low err_high]*5)
axis([0 10 -1000 1000])
xlabel('\fontsize{14}cycles per year')
ylabel('\fontsize{14}ppm^2/cpy')
title('\fontsize{16}Power Spectra of CO2 Records')
legend('\fontsize{12}La Jolla Station','\fontsize{12}Mauna Loa↙
Station', '\fontsize{12}South Pole','\fontsize{12}Uncertainty↙
Estimate','Location','northeast');

%% compute coherence

% compute cross covariance of LJO/MLO
ccLM=sum(LJO_ft(1:M+1,:).*conj(MLO_ft(1:M+1,:)),2)/N;
ccLM(2:end)=ccLM(2:end)*2;
% compute coherence
C_LM=abs(ccLM)./sqrt(LJO_spec.*MLO_spec);
phase_LM = atan2(-imag(ccLM),real(ccLM));
deltaPhase_LM = sqrt((1-C_LM.^2)./(abs(C_LM).^2*2*Nseg));

% compute cross covariance of MLO/SPO
ccMS=sum(MLO_ft(1:M+1,:).*conj(SPO_ft(1:M+1,:)),2)/N;
ccMS(2:end)=ccMS(2:end)*2;
% compute coherence
C_MS=abs(ccMS)./sqrt(MLO_spec.*SPO_spec);
phase_MS = atan2(-imag(ccMS),real(ccMS));
deltaPhase_MS = sqrt((1-C_MS.^2)./(abs(C_MS).^2*2*Nseg));

%% uncertainty estimate

alpha = 0.05; % 95% confidence level
gamma_threshold= sqrt(1-alpha^(1/(Nseg-1)));


%% plot the coherence

figure('name','Coherence Plots of CO2 Records');
subplot(2,1,1)
plot(frequency, C_LM,[frequency(1) frequency(end)],[gamma_threshold↙
gamma_threshold]);
axis tight;
```

```
xlabel('\fontsize{14}cycles per year')
ylabel('\fontsize{14}coherence')
title('\fontsize{16}Coherence of CO2 Records (LJO and MLO)')
legend('\fontsize{12}La Jolla vs. Mauna Loa','\fontsize{12}↙
Uncertainty Threshold','Location','northeast');

subplot(2,1,2)
plot(frequency, C_MS,[frequency(1) frequency(end)],[gamma_threshold↙
gamma_threshold]);
axis tight
xlabel('\fontsize{14}cycles per year')
ylabel('\fontsize{14}coherence')
title('\fontsize{16}Coherence of CO2 Records (MLO and SPO)')
legend('\fontsize{12}Mauna Loa vs. South Pole','\fontsize{12}↙
Uncertainty Threshold','Location','northeast');


%% plot the phase

figure('name','Phase Plots');
subplot(2,1,1)
semilogx(frequency,[phase_LM phase_LM+deltaPhase_LM phase_LM-↙
deltaPhase_LM]);
refline(0,pi);
refline(0,-pi);
xlabel('\fontsize{14}cycles per year')
ylabel('\fontsize{14}phase')
title('\fontsize{16}Phase Plot for Mauna Loa and La Jolla Coherence')
legend('\fontsize{12}phase', 'phase+delta phase','phase-delta↙
phase','Location','northwest');
axis tight

subplot(2,1,2)
semilogx(frequency,[phase_MS phase_MS+deltaPhase_MS phase_MS-↙
deltaPhase_MS]);
refline(0,pi);
refline(0,-pi);
xlabel('\fontsize{14}cycles per year')
ylabel('\fontsize{14}phase')
title('\fontsize{16}Phase Plot for Mauna Loa and South Pole↙
Coherence')
legend('\fontsize{12}phase', 'phase+delta phase','phase-delta↙
```

```
phase','Location','northwest');
axis tight
```