<u>Direct/bulk fluxes from the 2010 CALNEX Cruise – Version 1</u>

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DRAFT
October 15, 2010

This document is the Readme for *calnex2010_flux_10.txt, calnex2010_flux_hr.txt* and *calnex2010_PICflux_10.prn* files. The *_hr* refers to hourly averages and the *_10* refers to the 10-minute averages. This is a version which can simply be loaded in MATLAB. Both direct (covariance) and inertial-dissipation (ID) turbulent flux calculations are included in this present data. The period covered is DOY 134 (May 14, 2010) through DOY 158 (June 7, 2010). The graph below gives the ship track for the data period.

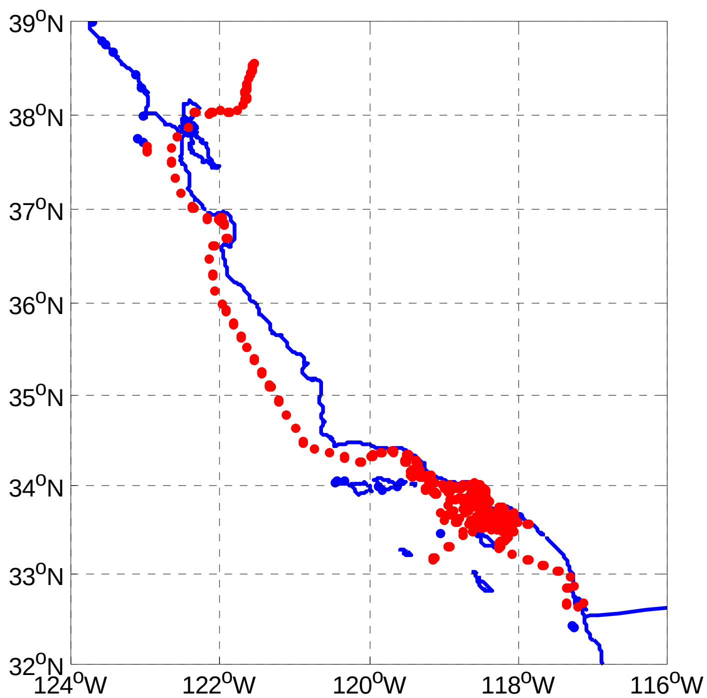

Figure 1. Track of R/V Atlantis during CALNEX 2010

1) <u>Column assignment for *calnex2010_flux_10.txt and calnex2010_flux_hr.txt* files</u>

The file is 54 columns:
- First column is the decimal day-of-year date
- Columns 2 to 11 are mean variables from the PSD system
- Columns 12 to 21 are turbulent fluxes (covariance, ID, and bulk)
- Columns 22 to 23 are the radiative fluxes
- Columns 24 is the rain rate

• Columns 25 to 27 are turbulence data quality indicators Columns 28 to 31 are the turbulent structure function parameters (indices of small-scale turbulence in the inertial subrange).
• Columns 32 to 33 are the minor (rain and Webb) heat flux components;
• Columns 34 to 35 are latitude and longitude;
• Columns 36 to 38 are the heights of the PSD wind, temperature, and humidity mean sensors.
• Columns 39 to 48 are mean variables from the ships sensors.
• Columns 49 to 53 are data computed from the LICOR-7500 open path IR sensor.
• Column 54 is the atmospheric pressure

The files can be directly acquired with a MATLAB 'load' statement. For instance:
`x=load('your_local_directory\ calnex2010_flux_10.txt');%read file with 10-min average data; set your local directory.` The columns assignment is as follows:

```
jdy=x(:,1);%day-of-year at beginning of time average
ushp=x(:,2);%doppler log, SCS (m/s) →not available
U=x(:,3);%true wind,PSD sonic (m/s)
dir=x(:,4);%true wind direction, PSD sonic (deg)
urel=x(:,5);%relative wind speed, PSD (m/s)
reldir=x(:,6);%relative wind dir (from),clockwise rel ship's bow, PSD sonic (deg)
head=x(:,7);%ship heading, deg clockwise rel north, PSD GPS
tsnk=x(:,8);%sea snake temperature, PSD, 0.05 m depth (C)
ta=x(:,9);%air temperature, PSD (C)%
qse=x(:,10);%sea surface specific humidity, from snake (g/kg)
qa=x(:,11);%air specific humidity, PSD (g/kg)
hsc=x(:,12);%sensible heat flux, covariance, PSD sonic anemometer(W/m^2)
hsib=x(:,13);%sensible heat flux, ID, PSD sonic anemometer(W/m^2)
hsb=x(:,14);%bulk sensible heat flux, (W/m^2)
hlc=x(:,15);%latent heat flux, covariance, (W/m^2)
hlib=x(:,16);%latent heat flux, ID, (W/m^2)
hlb=x(:,17);%bulk latent heat flux, W/m^2 (includes Webb et al. correction)
taucx=x(:,18);%covariance streamwise stress, PSD sonic anemometer (N/m^2)
taucy=x(:,19);%covariance cross-stream stress, PSD sonic anemometer (N/m^2)
tauib=x(:,20);%ID streamwise stress, PSD sonic anemometer (N/m^2)
taub=x(:,21);%bulk wind stress along mean wind, (N/m^2)
rs=x(:,22);%downward solar flux, PSD units (W/m^2)
rl=x(:,23);%downward IR flux, PSD units (W/m^2)
org=x(:,24);%rainrate, PSD STI optical rain gauge, uncorrected (mm/hr)
J=x(:,25);%ship plume contamination index
tiltx=x(:,26);%flow tilt at PSD sonic anemometer, earth frame
Jm=x(:,27);%ship maneuver index
ct=x(:,28);%ct^2 (K^2/m^.667)
cq=x(:,29);%cq^2 ((g/kg)^2/m^.667)
cu=x(:,30);%cu^2 ((m/s)^2/m^.667)
cw=x(:,31);%cw^2 ((m/s)^2/m^.667)
hrain=x(:,32);%rain heat flux,Gosnell et al 1995, JGR, 18437-18442, (W/m^2)
hlwebb=x(:,33);%correction to measured latent heat flux, Webb et al.
lat=x(:,34);%latitude, deg (SCS pcode)
lon=x(:,35);%longitude, deg (SCS pcode)
zu_psd=x(:,36);%height of mean wind sensor, 19.2 m
zt_psd=x(:,37);%height of mean air temperature sensor, 19 m
zq_psd=x(:,38);%height of mean air humidity sensor, 19 m
%***** ships imet and scs data
sog=x(:,39);%speed over ground, SCS gps, (m/s)
U_scs=x(:,40); %true wind speed, imet propvane anemometer (m/s)
dir_scs=x(:,41);%true wind direction (from),clockwise rel north, imet,(deg)
cog=x(:,42);%%course over ground, SCS gps, (m/s)
```

```
tsg=x(:,43);%tsg water temperature, 5 m depth, (C)
ta_im=x(:,44);%imet air temperature (C)
qs_tsg=x(:,45);%imet bulk water specific humidity (g/kg)
qa_im=x(:,46);%imet air specific humidity, (g/kg)
rs_im=x(:,47);%imet solar flux, (W/m^2)
rl_im=x(:,48);%imet IR flux (W/m^2) – not connected for neaqs
wco2_lic=x(:,49);%LICOR CO2 flux, (micatm m/s)
q_lic=x(:,50);%Specific humidity from LICOR (g/kg)
sgq_lic=x(:,51);%Standard deviation of specific humidity from LICOR (g/kg)
co2_lic=x(:,52); %CO2 concentration from Licor (umol/mol)
sgC_lic=x(:,53);%Standard deviation of CO2 concentration from LICOR
(microatm)
press=x(:,54); %Atmospheric pressure (mb)
```

Notes:
• In processing the 10-min data to one-hr averages, only the filtered data were used in averaging the turbulence variables. If there were no valid values in the 1-hr interval, the turbulence variables were set to NaN. The quality criteria were subdivided in two parts:

- A value of *J*=0 implies no ship contamination.
- A value of *Jm*<3 implies no significant maneuver during the average.

• Bulk estimates of air sea fluxes were computed using the COARE bulk algorithm version 3.0.
• Because the IR hygrometer detects water vapor mass concentration (ρ_v in kg/m^3), the water vapor -velocity correlation must be corrected as per Webb et al ($H_{latent} = L_e <w' \rho_v'> +$ hl_webb). The values given for covariance and ID latent heat fluxes in the file are $L_e<w' \rho_v'>$. Values for hl_webb are included in column 33. This should be applied to the covariance and ID values. It is already included in the bulk values given here.

• Both latent and CO2 fluxes are computed from the LICOR-7500 open path IR sensor. The CO2 fluxes have been corrected for the humidity Webb effect but not for the temperature Webb effect.

• Sensible heat flux was computed from vertical velocity -sonic temperature covariance and Inertial-dissipation (ID) methods. The humidity contribution to sonic temperature was removed using the bulk latent heat flux.

• Turbulent fluxes are computed by converting the anemometer 3-component velocities to fixed earth coordinates, correcting the fast time series for ship motion, and resetting the coordinate system normal to the 10-min mean flow through one rotation about the original vertical and one tilt. The variable *tiltx* gives the tilt used for the computation. Experience shows that tilts greater than about 10 deg give questionable fluxes.

2) <u>Column assignment for *calnex2010_PICflux_10.prn* file</u>

The file is 19 columns:
• First column is the decimal day-of-year date
• Columns 2 is CO2 turbulent flux from the University of Hawaii (UH) PICARRO unit, and is referred as ‘PBY’ in what follows.
Columns 3 to 5 are CO2, H2O and CH4 turbulent flux from a second PICARRO unit, referred as ‘PCO’.
• Columns 6 to 7 are lag times evaluated by cross-correlation technique. These values were computed for reference only, and lag times obtained from a puff-system were used instead.

• Columns 8 to 19 are the mean concentrations as well as additional criteria used to determine and reject unstationary conditions.

```
PIC_doy=PICview(:,1); day-of-year at beginning of time average
wpby_CO2=PICview(:,2);    %PBY CO2 flux, (umol/mol m/s)
wpco_CO2=PICview(:,3);    %PBY CO2 flux, (umol/mol m/s)
wpco_H2O=PICview(:,4);    %PBY H2O flux, (g/kg m/s)
wpco_CH4=PICview(:,5);    %PBY CH4 flux, (umol/mol m/s)
dtpby=PICview(:,6);       %PBY lag time from cross-correlation*10 (s)
dtpco=PICview(:,7);       %PCO lag time from cross-correlation*10 (s)
stdpby_CO2=PICview(:,8);  %Standard deviation of PBY CO2 (umol/mol)
meanpby_CO2=PICview(:,9); %CO2 concentration from PBY (umol/mol)
slopepby_CO2=PICview(:,10);% regression slope of PBY CO2 /10 (umol/mol/s)
stdpco_CO2=PICview(:,11); %Standard deviation of PCO CO2 (umol/mol)
meanpco_CO2=PICview(:,12);%CO2 concentration from PCO (umol/mol)
slopepco_CO2=PICview(:,13); % regression slope of PCO CO2 /10 (umol/mol/s)
stdpco_H2O=PICview(:,14); %Standard deviation of PBY H2O (g/kg)
meanpco_H2O=PICview(:,15);%Specific humidity from PCO (g/kg)
slopepco_H2O=PICview(:,16); % regression slope of PCO H2O /10 (umol/mol/s)
stdpco_CH4=PICview(:,17); %Standard deviation of PBY CH4 (umol/mol)
meanpco_CH4=PICview(:,18);%CH4 concentration from PCO (umol/mol)
slopepco_CH4=PICview(:,19); % regression slope of PCO CH4 /10 (umol/mol/s)
```

• Check the notebook file *CalNex Notes BWB.pdf* for more information on the operation timelines of the two PICARRO units.

• To compute fluxes, a puff system was used (with CO2 reference). The lag time was calculated as the difference between the initial puff time and the time it takes the system's response to reach 1-1/e of its final value. Values from the puff tests and from cross-correlation technique are represented below for both units. For the flux calculation, constant lag times were used through the entire cruise: about 19.4s for the pby unit and about 8.5s for the pco unit.

In addition to the quality criteria J and Jm from *calnex2010_flux_10.txt* file, two criteria have been added to determine and reject unstationary conditions.

• the standard deviation of the 10 Hz data within the ten minute averaging. This indicates the degree of fluctuation in concentration over each 10-min measurement period.

• the slope from a linear regression applied to the 10-min data. This indicates concentration changes/trends over the 10-min period.

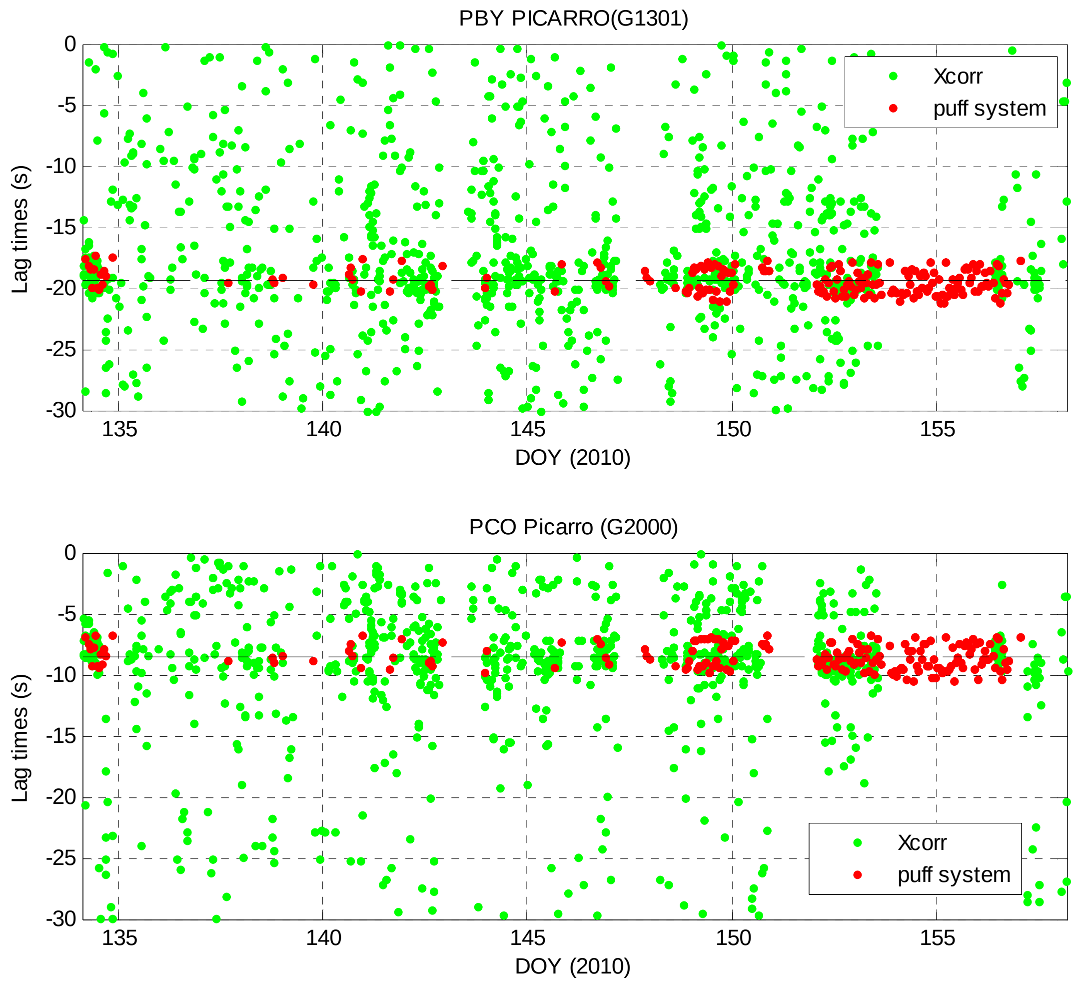

Figure 2. 10-min lag time results from the puff system (red dots), the cross-correlation calculation (green dots) for both the pby unit (top panel) and pco unit (lower panel). The back lines represent the value used in the flux computation.

1) Time series

Figures 3, 4 and 5 show the time series for stress, sensible heat, and latent heat. Figures 6, 7 and 8 show the time series for CO2, H2O and CH4 concentration, while figures 9, 10 and 11 shows the flux for the same variables.

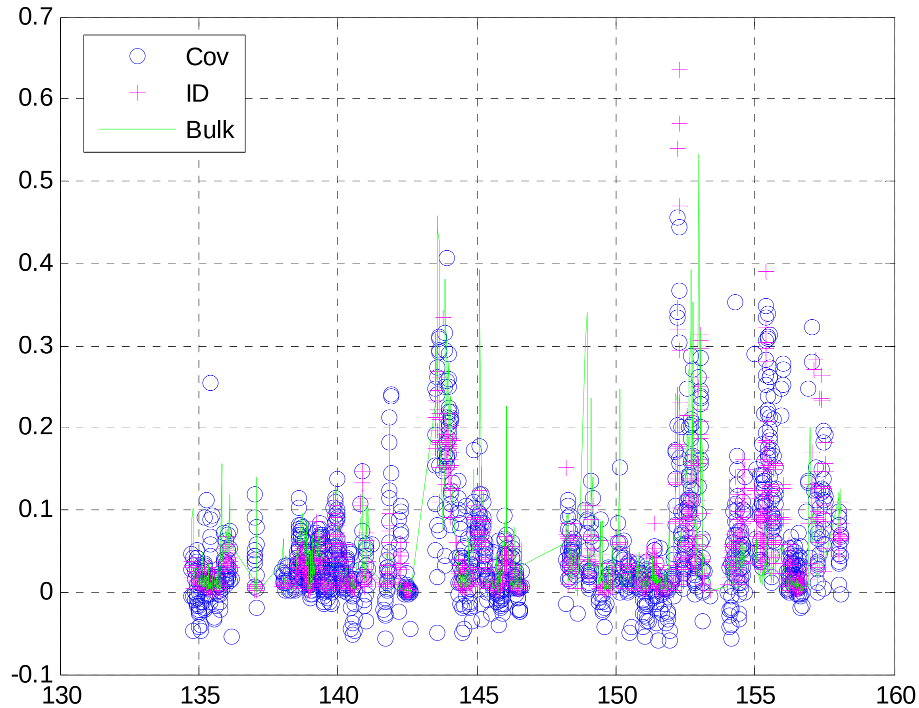

Figure 3. Time series of turbulent surface stress in CALNEX2010: green line - bulk estimate; magenta '+' - ID; blue circles - covariance measurement.

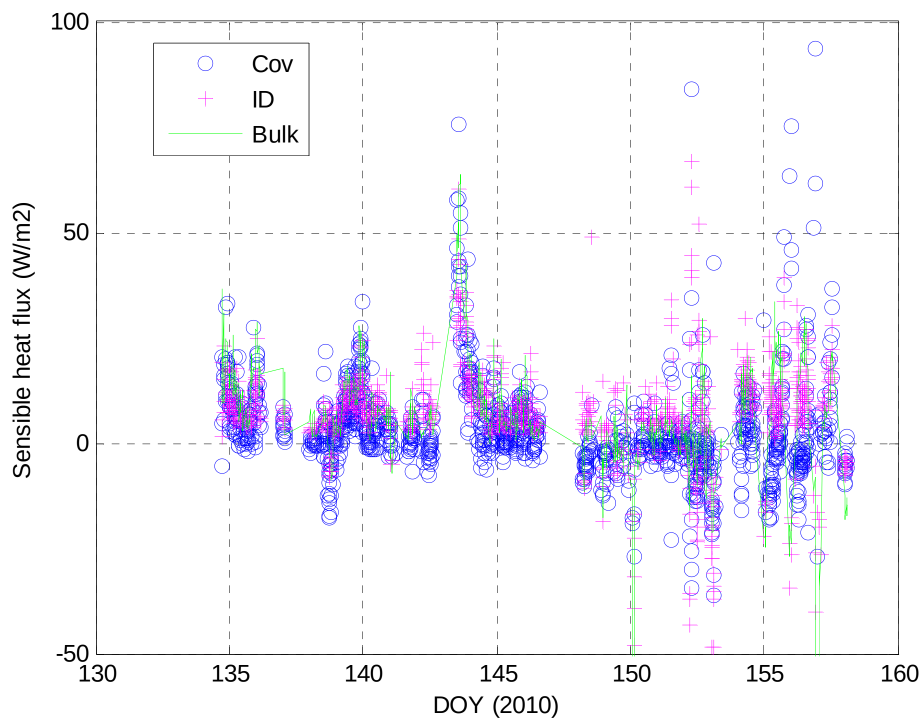

Figure 4. Time series of sensible heat flux in CALNEX2010: green line - bulk estimate; magenta '+' - ID; blue circles - covariance measurement.

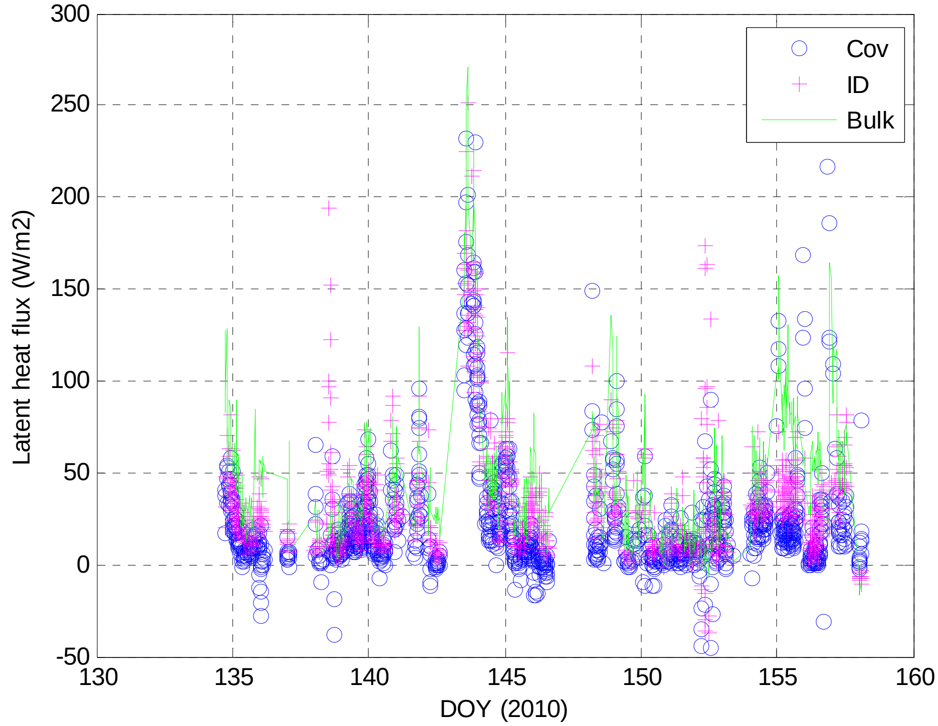

Figure 5. Time series of latent heat flux in CALNEX2010: green line - bulk estimate; magenta '+' - ID; blue circles - covariance measurement.

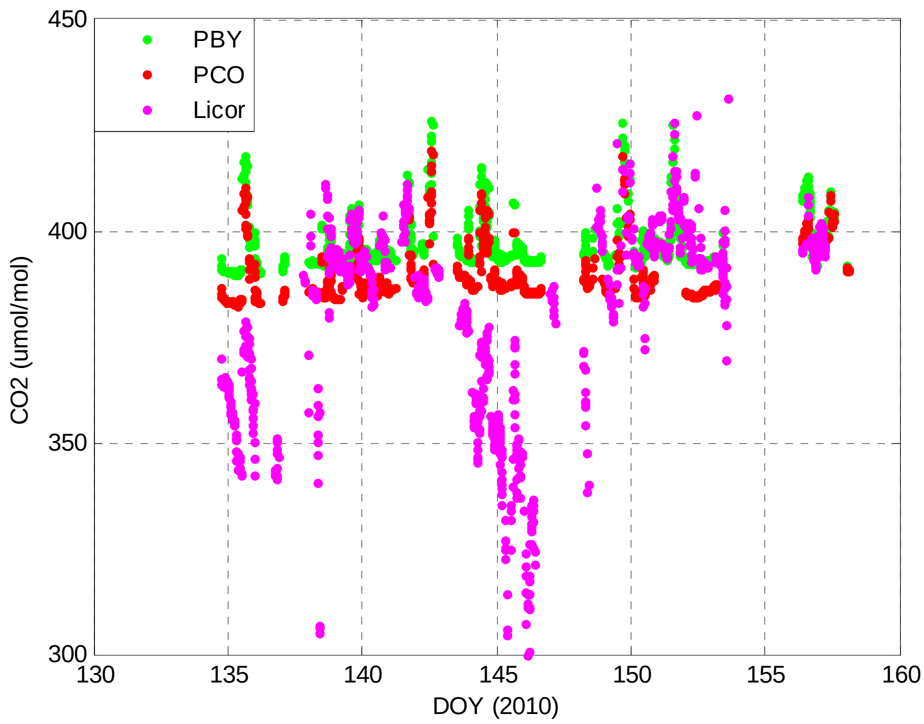

Figure 6. Time series of CO2 for CALNEX2010: green – PBY Picarro; red – PCO Picarro; Magenta - Licor.

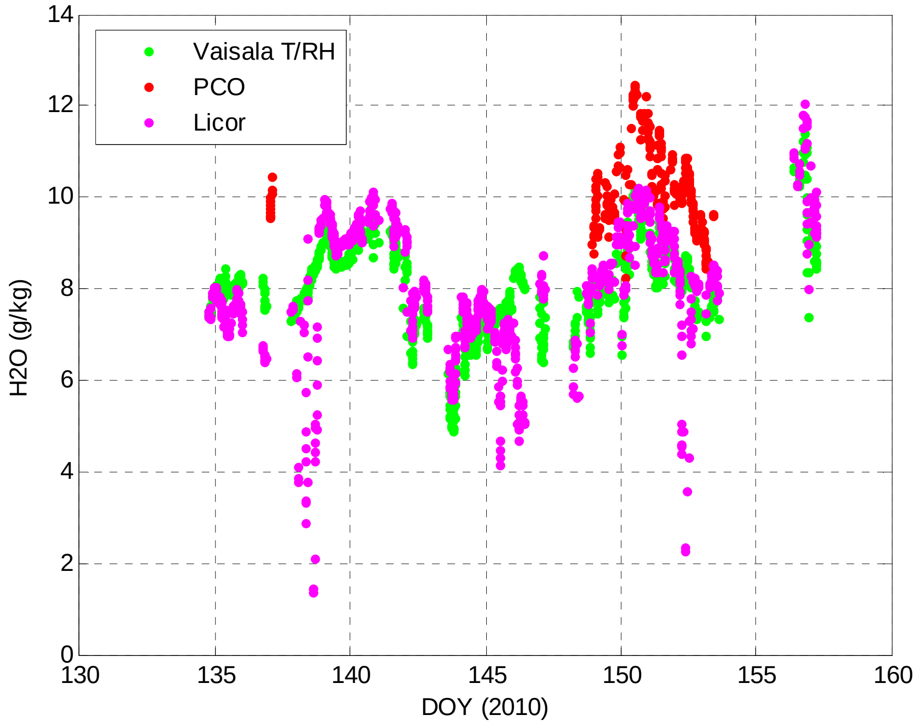

Figure 7. Time series of H2O for CALNEX2010: green – Vaisal T/RH sensor; red – PCO Picarro; Magenta - Licor.

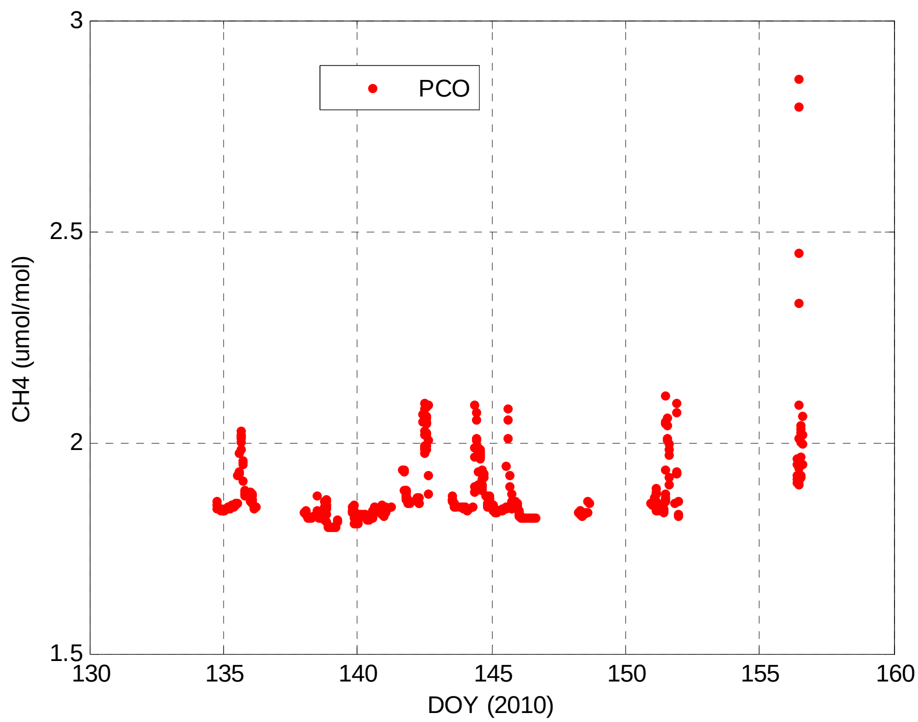

Figure 8. Time series of CH4 from PCO Picarro.

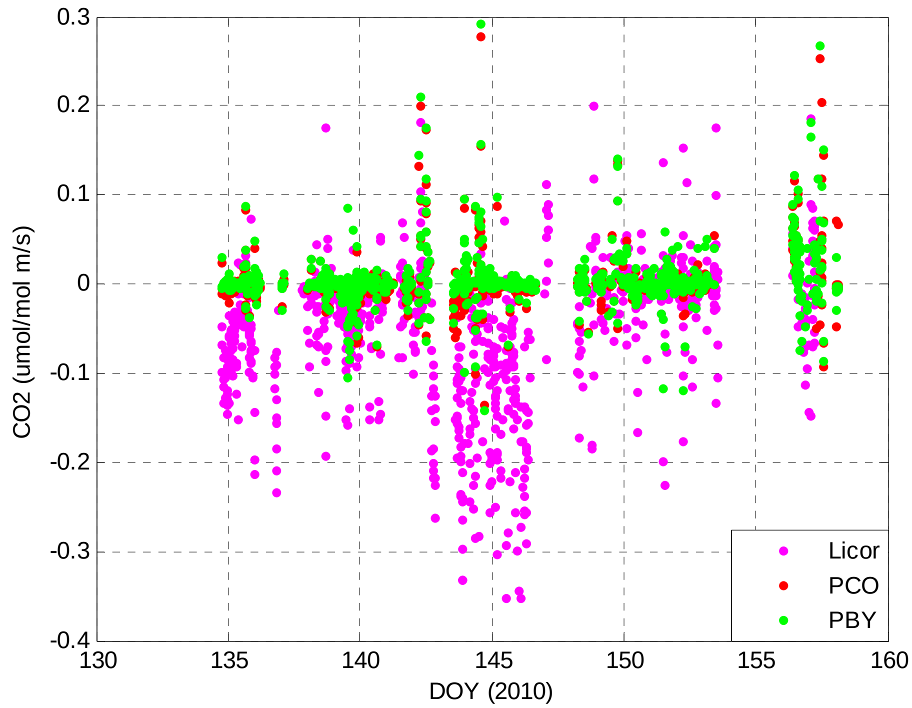

Figure 9. Time series of CO2 flux in CALNEX2010: green – PBY Picarro; red – PCO Picarro; Magenta - Licor.

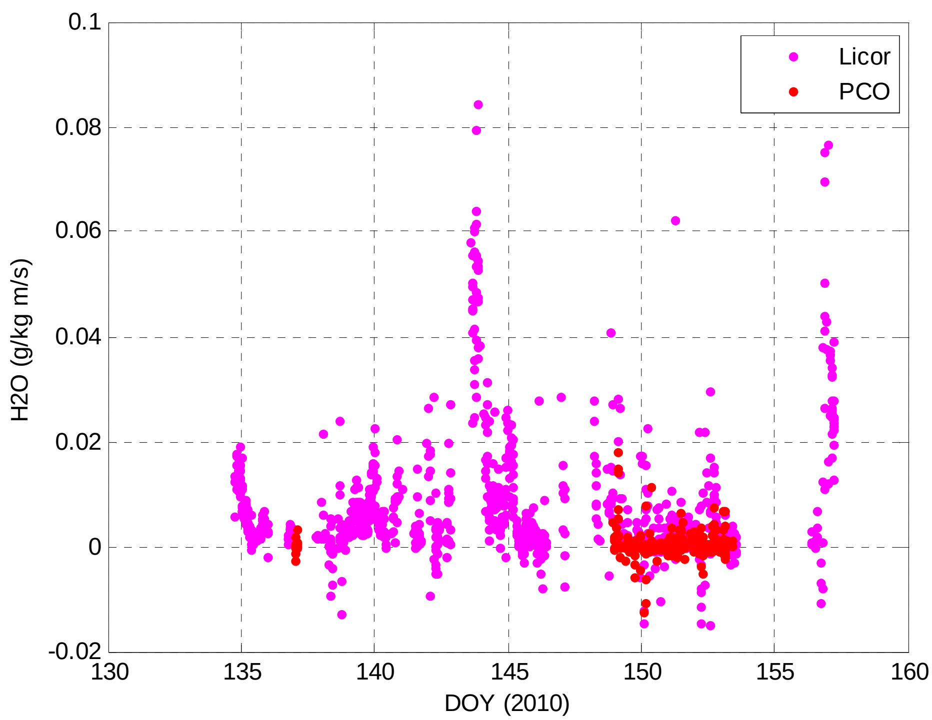

Figure 10. Time series of H2O flux in CALNEX2010: red – PCO Picarro; Magenta - Licor.

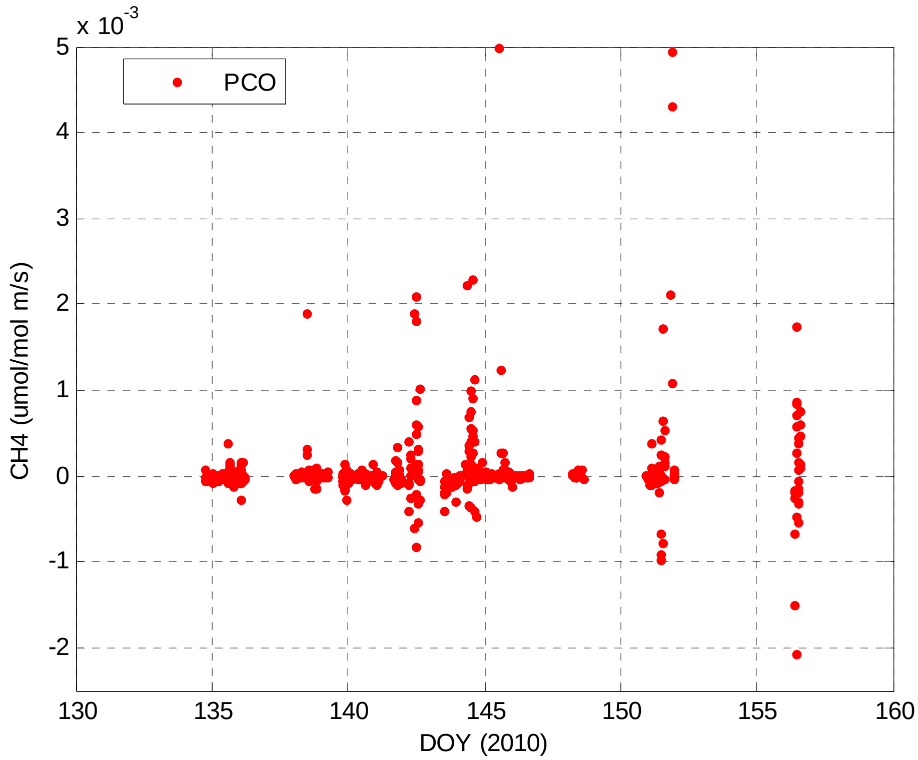

Figure 11. Time series of CH4 flux from PCO Picarro

2) <u>Spectral plots</u>

Below are spectra and co-spectra for CO2 measurements made during CALNEX2010.

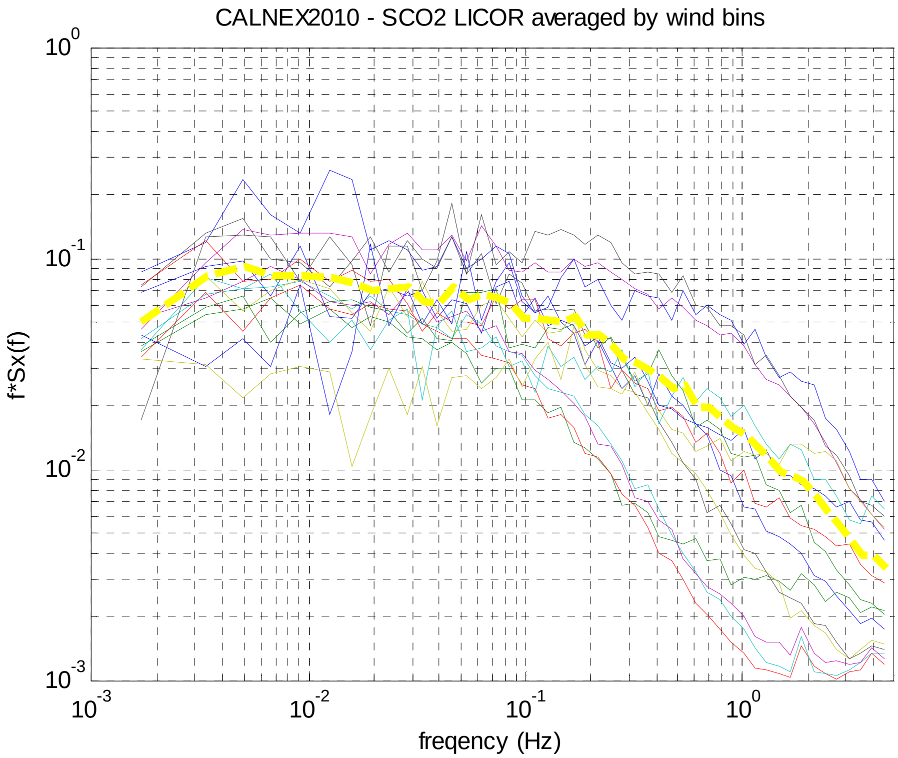

Figure 12. CO2 Spectra from Licor averaged by 1 m/s wind bins. The yellow dash line is the estimated spectra for the entire cruise.

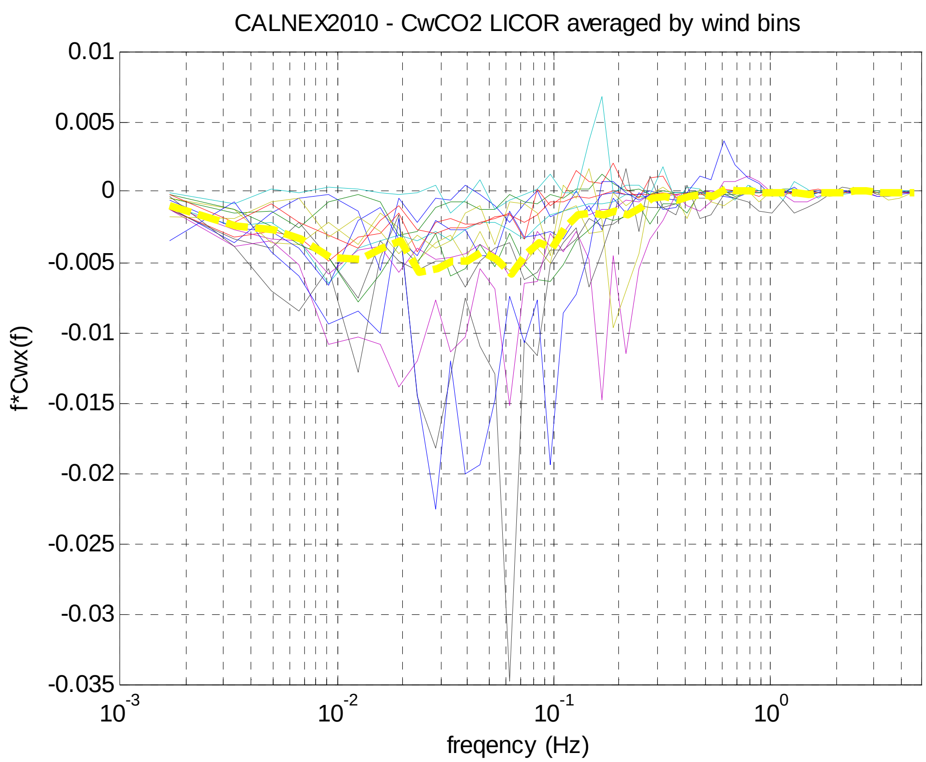

Figure 13. CO2 cospectra from Licor averaged by 1 m/s wind bins. The yellow dash line is the estimated cospectra for the entire cruise.

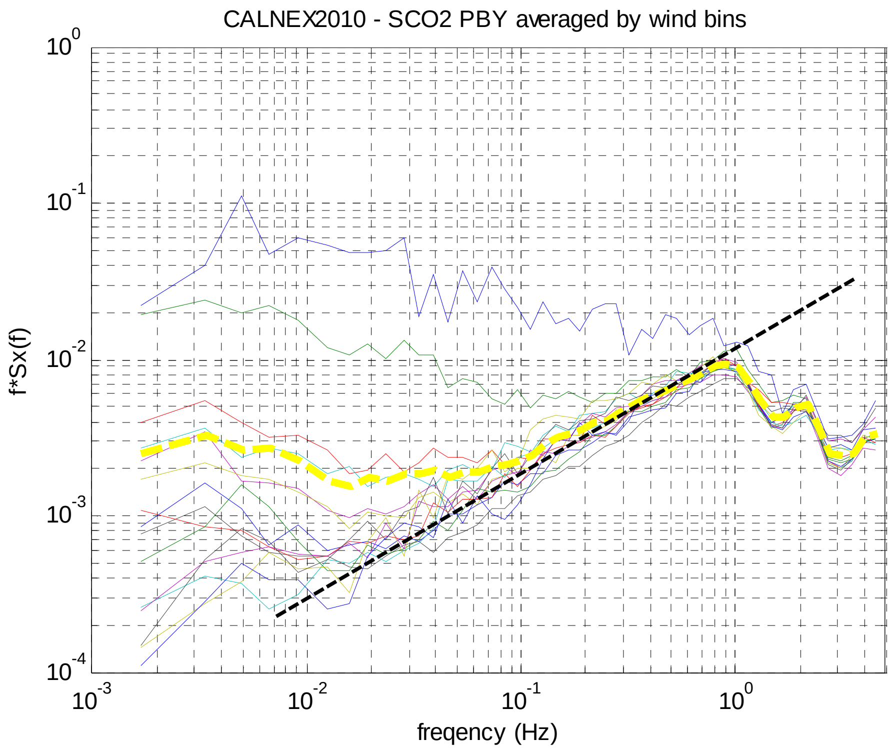

Figure 14. CO2 Spectra from PBY unit averaged by 1 m/s wind bins. The yellow dash line is the estimated spectra for the entire cruise, and the bold dashed line shows a slope of +1

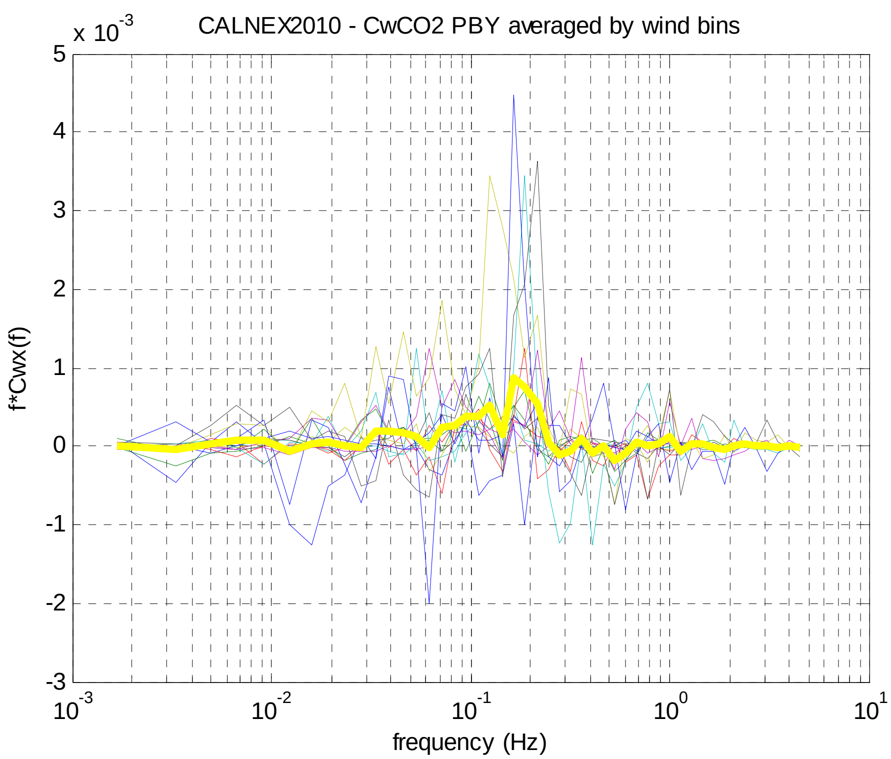

Figure 15. CO2 cospectra from PBY Picarro averaged by 1 m/s wind bins. The yellow dash line is the estimated pectra for the entire cruise.

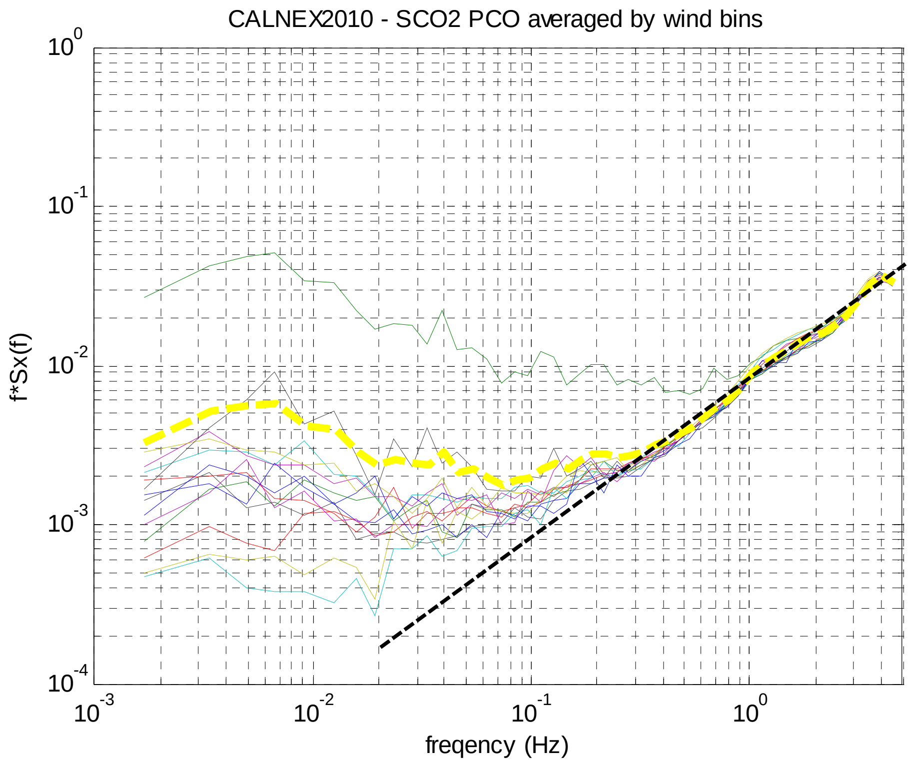

Figure 16. CO2 Spectra from PBY unit averaged by 1 m/s wind bins. The yellow dash line is the estimated spectra for the entire cruise, and the bold dashed line shows a slope of +1

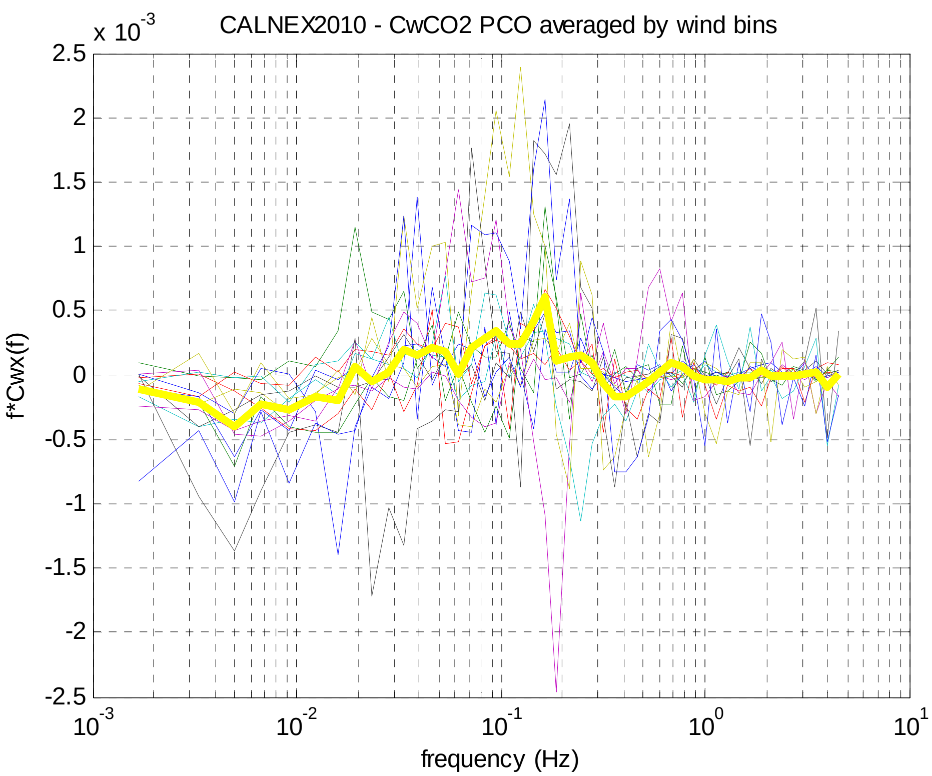

Figure 17. CO2 cospectra from PCO Picarro averaged by 1 m/s wind bins. The yellow dash line is the estimated pectra for the entire cruise.

Similar plots are obtained for H2O and CH4. Finally, let's check the sonic itself by plotting w'u', w'v' and w'T' cospectra (figures 18, 19 and 20).

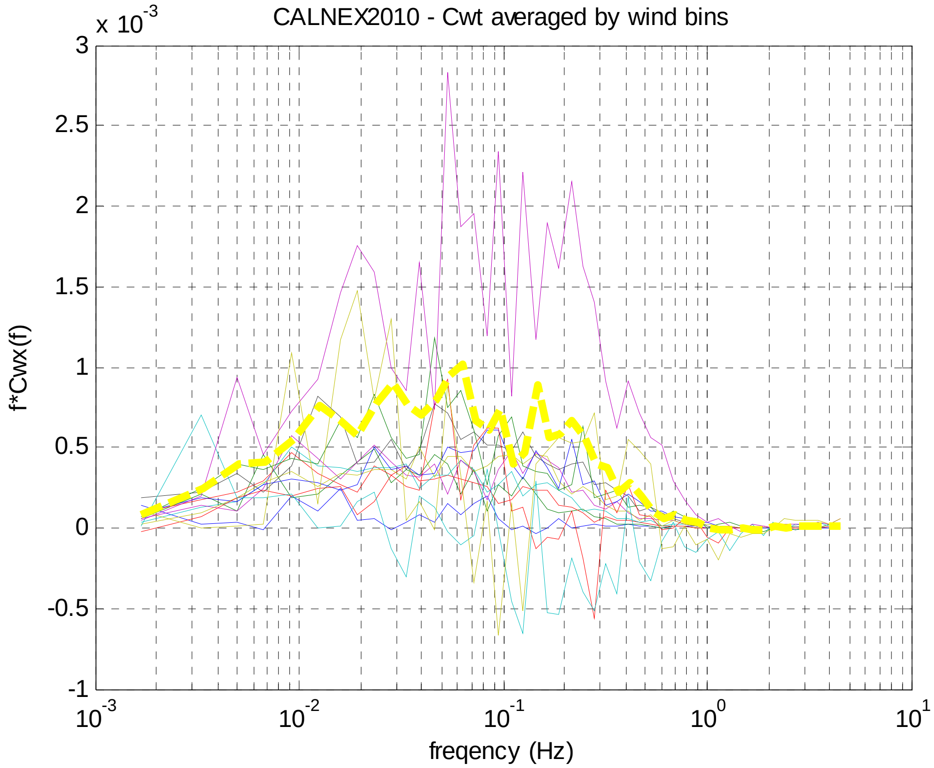

Figure 18. Temperature cospectra (w'T') from PSD sonic averaged by 1 m/s wind bins. The yellow dash line is the estimated pectra for the entire cruise.

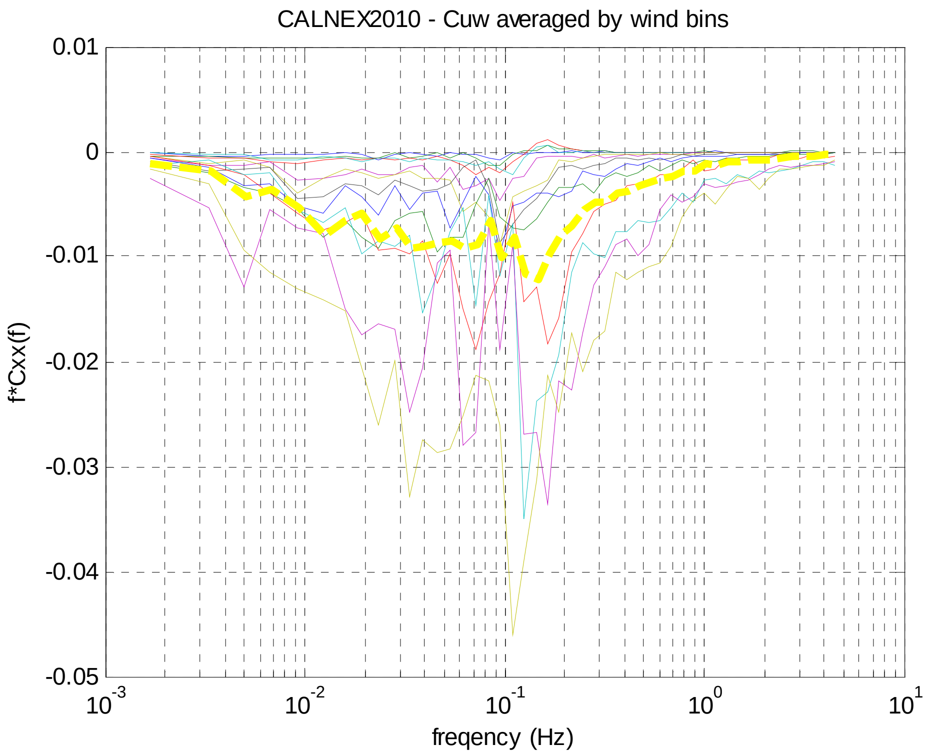

Figure 19. w'u' cospectra from PSD sonic averaged by 1 m/s wind bins. The yellow dash line is the estimated pectra for the entire cruise.

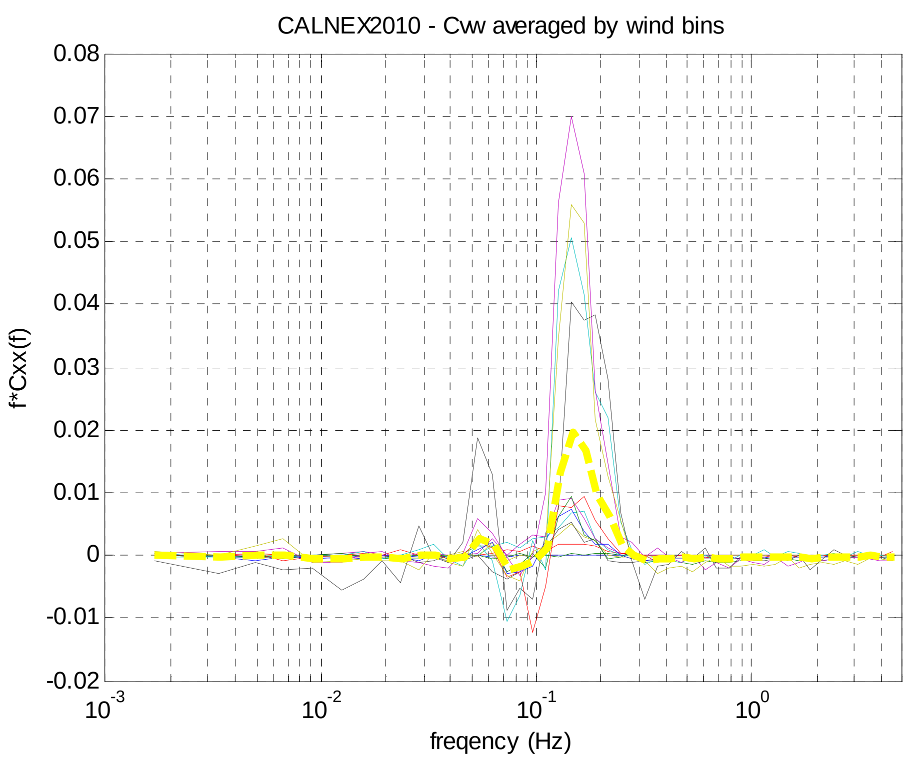

Figure 20. w'v' cospectra from PSD sonic averaged by 1 m/s wind bins. The yellow dash line is the estimated pectra for the entire cruise.

3) <u>Summary</u>

It appears that the PICARRO units present too much white noise (see Spectra), and maybe has a low SNR? Note here that no sample tube smoothing correction has been applied yet.

From the puff tests, the response times (and thus cutoff frequencies) were estimated, as illustrated on Figure 21 below.

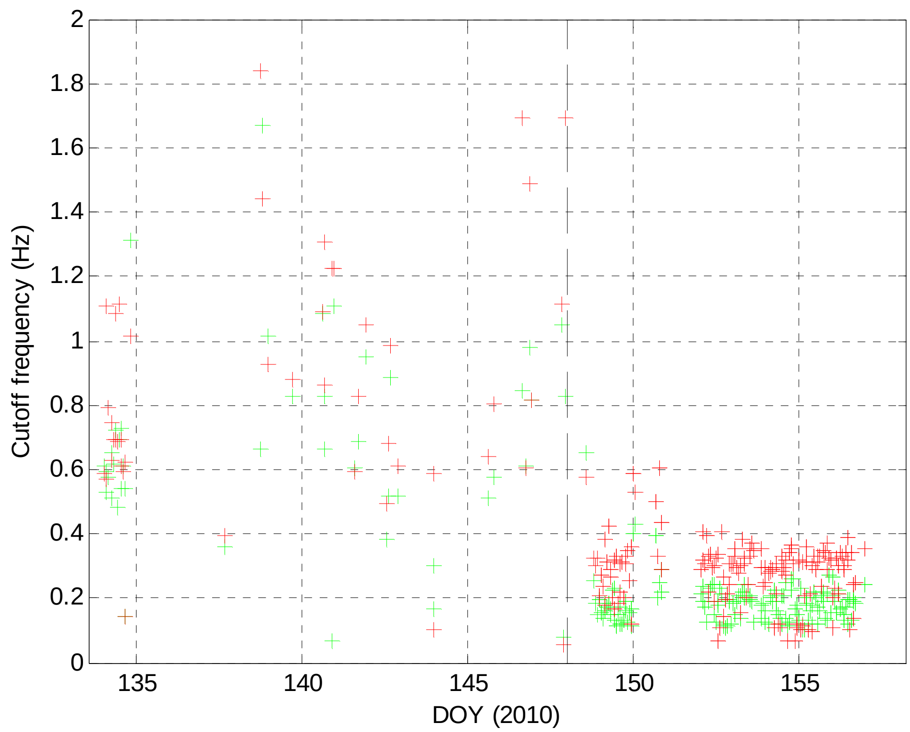

Figure 21. Cutoff frequency obtained during CALNEX2010: red – PCO; Green - PBY. The vertical dash line at doy 148 indicates the transition leg1-leg2

If we consider the fact the puff system was 'maybe' not fully operational during leg1, the estimated cutoff frequencies are thus 0.2Hz for the PBY unit and 0.3Hz for the PCO unit. Need to check with theory estimate (needs Byron measurements/estimates). Or maybe the sampling flow rate was changed between the 2 legs?