



## Applied Remote Sensing Training (ARSET) Program

### Applications of Carbon Dioxide Measurements for Climate-Related Studies (2024)

## Homework Questions

### Question 1

When were OCO-2 and OCO-3 launched into space?

Answers: (bold correct)

- a. OCO-2 was launched in 2014 and OCO-3 in 2020.
- b. OCO-2 was launched in 2012 and OCO-3 in 2020.
- c. OCO-2 was launched in 2020 and OCO-3 in 2013.
- d. **OCO-2 was launched in 2014 and OCO-3 in 2019.**

Feedback:

OCO-2 was launched in 2014 and OCO-3 in 2019.

### Question 2

OCO-3 spatial coverage spans between 52 degrees North and South latitudes.

Answers: (bold correct)

- a. **True**
- b. False

### Question 3

OCO-2 has the following characteristics:

Answers: (bold correct)

- a. Its temporal repeat is every 12 days and observations are made at ~8:30 a.m. local time.
- b. Its temporal repeat is every 10 days and observations are made at ~10:30 a.m. local time.

- c. **Its temporal repeat is every 16 days and observations are made at ~1:30 p.m. local time.**
- d. Its temporal repeat is every 16 days and observations are made at ~5:30 p.m. local time.

Feedback:

Its temporal and repeat are every 16 days and observations are made at ~1:30 p.m. local time.

## Question 4

OCO-2 and OCO-3 have the following observation modes:

Answers: (bold correct)

- a. Nadir, Glint, and Azimuth
- b. Nadir, Glint, and SAM
- c. Nadir, Glint, and Alpha
- d. **Nadir, Glint, and Target**

## Question 5

OCO-3 has an additional mode called the Snapshot Area Mapping (SAM) mode, which is ideal for studying urban emissions.

Answers: (bold correct)

- a. **True**
- b. False

## Question 6

Spaceborne measurements of CO<sub>2</sub> can be derived from instruments that measure in near infrared wavelengths (such as OCO-2, OCO-3, and GOSAT) and from instruments that measure in thermal infrared wavelengths (such as TES, AIRS, and CrIS). Which of the statements below is true? (Pick 1)

Answers: (bold correct)

- a. **Near infrared spectral measurements can provide sensitivity to variations in CO<sub>2</sub> throughout the atmospheric column and can be used in the estimation of sources and sinks.**
- b. Measurements of CO<sub>2</sub> spectral bands in the near infrared and thermal infrared measurements of CO<sub>2</sub> provide equivalent vertical sensitivity.
- c. Near infrared spectral measurements can provide information on the fine-scale vertical structure of the shape of the profile of atmospheric CO<sub>2</sub>.

Feedback:

The correct answer is A. Answer B is incorrect. Near infrared measurements can provide sensitivity to variations in CO<sub>2</sub> throughout the atmospheric column, while thermal infrared measurements provide

sensitivity primarily to variations in CO<sub>2</sub> in the mid to upper troposphere. Answer C is incorrect. No current spaceborne CO<sub>2</sub> measurement can provide information on the fine-scale vertical structure of the shape of atmospheric CO<sub>2</sub>.

### Question 7

XCO<sub>2</sub> is the mixing ratio of a single point in the atmosphere, which is a measure of the amount of carbon dioxide in the entire atmosphere.

Answers: (bold correct)

- a. True
- b. False**

Feedback:

XCO<sub>2</sub> is the atmospheric column average volume mixing ratio, which is a measure of the amount of carbon dioxide in the atmosphere.

### Question 8

What are the factors affecting the quality of the OCO measurements?

Answers: (bold correct)

- a. Clouds
- b. Optically Thick Aerosols
- c. High Solar Zenith Angles
- d. Mountainous Terrain
- e. All of the Above**

### Question 9

The XCO<sub>2</sub> measurement from OCO-2/OCO-3 is directly comparable to an in situ measurement at a surface site or a single point in the atmosphere.

Answers: (bold correct)

- a. True
- b. False**

Feedback:

They are not directly comparable because the satellite observation is a measurement of the average CO<sub>2</sub> concentration in the atmospheric column while the in situ measurement is not.

### Question 10

XCO<sub>2</sub> measurements from OCO-2 and OCO-3 can be combined together in an analysis.

Answers: (bold correct)

- a. **True**
- b. False

## Question 11

The OCO-2 Level-3 data are global daily products that have not been gap-filled.

Answers: (bold correct)

- a. True
- b. **False**

## Question 12

Which OCO files are recommended for analysis because they are smaller in size and contain just the XCO<sub>2</sub> data and have already been pre-screened, quality-flagged (filtered), and bias-corrected?

Answers: (bold correct)

- a. The Full Physics Files
- b. The Beta Files
- c. The X Files
- d. **The Lite Files**

## Question 13

When using the "xco2\_quality\_flag" included with the Lite files, which value indicates that the data is good?

Answers: (bold correct)

- a. **0**
- b. 1
- c. 2
- d. 3

## Question 14

The vertical sensitivity of a XCO<sub>2</sub> measurement is described by a quantity that is supplied in the Level2 Lite product files. What is this quantity?

Answers: (bold correct)

- a. The Quality Flag
- b. The Bias Corrected Value
- c. **The Averaging Kernel**

#### d. The XCO<sub>2</sub> Uncertainty

Feedback:

The averaging kernel, which describes the sensitivity of a remotely sensed measurement to the true atmosphere. The averaging kernel can be slightly different for each sounding/measurement, since it depends on the surface and atmospheric conditions.

The quality flag provides a recommendation to the user on whether or not the reported measurement is considered "good" or not. In the OCO-2 and OCO-2 Lite product files, an "xco<sub>2</sub>\_quality\_flag = 0" denotes "good" measurements. A bias correction has been applied to the XCO<sub>2</sub> values in the OCO-2 and OCO-3 Level 2 Lite product files. This bias correction does not provide information on the vertical sensitivity of the measurement.

The OCO-2 and OCO-3 Level 2 product files contain a quantity "xco<sub>2</sub>\_uncert" that provides a measure of the estimated uncertainty for each individual sounding/measurement

### Question 15

OCO-2 and OCO-3 data are freely available and can be accessed through the NASA GES DISC data archive center.

Answers: (bold correct)

- a. **True**
- b. False

Feedback:

The data is indeed freely available. They can be accessed through the Goddard Earth Sciences Data and Information Services Center (GES DISC).

### Question 16

The estimated accuracy of XCO<sub>2</sub> from OCO-2 and OCO-3 when compared to the TCCON network is the following:

Answers: (bold correct)

- a. Less than 45 ppmv for OCO-2 (v. 11.1) and less than 50 ppmv for OCO-3 (v. 10.4)
- b. Less than 20 ppmv for OCO-2 (v. 11.1) and less than 25 ppmv for OCO-3 (v. 10.4)
- c. Less than 5 ppmv for OCO-2 (v. 11.1) and less than 7 ppmv for OCO-3 (v. 10.4)
- d. **Less than 0.8 ppmv for OCO-2 (v. 11.1) and less than 1 ppmv for OCO-3 (v. 10.4)**

Feedback:

Less than 0.8 ppmv for OCO-2 (v. 11.1) and less than 1 ppmv for OCO-3 (v. 10.4)

## Question 17

What can we do with OCO-2 and OCO-3 measurements? Select all that apply.

Answers: (bold correct)

- a. **Show the global rise of atmospheric CO2 over time**
- b. **Quantify how CO2 emissions are offset by natural carbon sinks**
- c. **Show two-way interactions between carbon and climate**
- d. **Accurately quantify CO2 emissions from power plants and cities.**

## Question 18

Carbon fluxes are the direction and rate of transfer of carbon between Earth's carbon pools, such as the oceans, atmosphere, land, and other living things.

Answers: (bold correct)

- a. **True**
- b. False

## Question 19

The change in atmospheric CO2 concentration at any location is related to:

Answers: (bold correct)

- a. Local Surface Carbon Fluxes
- b. Atmospheric Lateral Transport
- c. **Local Surface Carbon Fluxes and Atmospheric Lateral Transport**

## Question 20

How are surface carbon fluxes linked with atmospheric CO2 concentrations?

Answers: (bold correct)

- a. There is no way to do this
- b. With land surface models
- c. With ocean models
- d. **With atmospheric transport models**

## Question 21

The process to calculate carbon fluxes with atmospheric CO2 concentrations is called atmospheric CO2 flux inversion.

Answers: (bold correct)

- a. True
- b. False

## Question 22

How does seasonality affect carbon fluxes?

Answers: (bold correct)

- a. Land carbon fluxes have much stronger seasonality than air-sea fluxes.
- b. Fossil fuel emissions have a weaker seasonality than land carbon fluxes.
- c. Air-sea fluxes have a stronger seasonality than land carbon fluxes.
- d. A and B**
- e. B and C

## Question 23

What carbon cycle process drives the large magnitude of the CO<sub>2</sub> seasonal cycle in the northern hemisphere?

Answers: (bold correct)

- a. The seasonal changes of fossil fuel emissions in the Northern Hemisphere
- b. The seasonal changes of air-sea carbon fluxes in the Northern Hemisphere
- c. The seasonal changes of atmospheric transport patterns in the Northern Hemisphere
- d. The seasonal changes of terrestrial biosphere photosynthetic activity in the Northern Hemisphere**

Feedback:

The correct answer is D. Photosynthetic activity is the primary cause of CO<sub>2</sub> seasonal swings, so regions with more plants will experience larger CO<sub>2</sub> fluctuations. The Northern Hemisphere (NH) and the tropics have most of the land plants. Because the temperature has much smaller seasonal variation in the tropics, the seasonal swings of CO<sub>2</sub> are more pronounced in the NH, where the seasonal changes in temperature result in large differences in plant photosynthesis from summer to winter. Fossil fuel emissions, air-sea carbon fluxes, and atmospheric transport all have seasonal changes, but the magnitude is much smaller than the net carbon fluxes of the terrestrial biosphere in the NH.

## Question 24

24. What carbon cycle process is the primary cause of the increase of atmospheric CO<sub>2</sub> concentration?

Answers: (bold correct)

- a. Fossil Fuel Emissions**
- b. Terrestrial Biosphere Fluxes
- c. Air-Sea Carbon Fluxes

#### d. Volcanic Eruptions

Feedback:

The correct answer is A. The burning of fossil fuels is the primary driver of the increase in atmospheric CO<sub>2</sub> concentration. Currently, the annual fossil fuel emission is about 10 gigaton carbon per year (GtC/year), causing about a 2.5 parts per million (ppm) increase in atmospheric CO<sub>2</sub> concentration, equivalent to about 5.0 GtC. The rest of the fossil fuel emissions have been absorbed by either land or ocean, so the land and ocean carbon cycle act as buffers for atmospheric CO<sub>2</sub> increase. Volcanic eruptions release carbon to the atmosphere, but the magnitude of annual fossil fuel emissions is 100-300 time larger than the CO<sub>2</sub> emissions from volcanic eruptions.

### Question 25

25. What natural climate variability caused the anomalously large CO<sub>2</sub> increase in 2015 and 2016?

Answers: (bold correct)

- a. Flooding over tropical continents
- b. Drought and high temperature over the tropical continents caused by the 2015-2016 El Niño**
- c. Drought and high temperature over the extra-tropics
- d. The anomalous tropical ocean current during the 2015-2016 El Niño

Feedback:

The correct answer is B. The 2015-2016 El Niño was the largest El Niño event of the 21st century. During this event, sea surface temperatures over the central and eastern Pacific Ocean became much warmer, causing severe drought in tropical South America and tropical Asia, and high temperatures in tropical Africa through changes in atmospheric circulation. The drought led to reduced plant growth in tropical South America and Asia and increased fire activities in tropical Asia, while the high temperature in tropical Africa led to increased carbon release through soil respiration process. These processes together caused the anomalously large CO<sub>2</sub> increase in 2015-2016.

### Question 26

The source of carbon emissions within cities can happen from various sectors and not necessarily from a single source.

Answers: (bold correct)

- a. True**
- b. False

### Question 27

When performing top-down estimates of CO<sub>2</sub> it is not important to account for the background values of CO<sub>2</sub>.

Answers: (bold correct)

- a. True
- b. False**

Feedback:

When performing top-down estimates of CO<sub>2</sub> it is very important to account for the background values of CO<sub>2</sub>.

## Question 28

CO<sub>2</sub> emitters from large point sources cannot be detected by OCO-2 or OCO-3.

Answers: (bold correct)

- a. True
- b. False**

Feedback:

CO<sub>2</sub> emissions from large point sources can be detected with OCO-2/OCO-3.

## Question 29

29. SAM acquisitions: (Select all that apply)

Answers: (bold correct)

- a. Are useful for quantifying changes in emissions occurring in urban areas.**
- b. Together with co-emitted species (e.g., NO<sub>2</sub> or CO), can aid in sectoral attribution.**
- c. Have the potential to monitor the socioeconomic/regional characteristics of global urban emissions.**
- d. Help increase transparency in carbon accounting and aid in the decision-making process.**

## Question 30

In the first Jupyter Notebook demonstration titled "arset-oco-earthaccess-download-analysis-..." - where did you see the greatest CO<sub>2</sub> concentrations in the "OCO-2 Column-averaged CO<sub>2</sub> Monthly Average for March 2016" figure?

Answers: (bold correct)

- a. Japan
- b. Australia
- c. Southern Hemisphere
- d. Northern Hemisphere**

### Question 31

In the first Jupyter Notebook demonstration titled "arset-oco-earthaccess-download-analysis-..." - where did you see the largest CO<sub>2</sub> differences in the "OCO-2 Column Averaged CO<sub>2</sub> Monthly Mean Difference: March 2016-2015" figure?

Answers: (bold correct)

- a. Pacific Ocean
- b. Tropical South America**
- c. Europe
- d. United States of America

### Question 32

In the second Jupyter Notebook demonstration titled "arset-oco-earthaccess-download-analysis-2024-test-fluxes-..." - what is the largest difference between fluxes over land between March and July 2016? Select all that apply.

Answers: (bold correct)

- a. There is no difference in carbon fluxes in the northern hemisphere between July and March.
- b. The northern hemisphere is a carbon source in March and a carbon sink in July.**
- c. The northern hemisphere is a carbon source in July and a carbon sink in March.

### Question 33

In the third Jupyter Notebook demonstration titled "ARSET OCO-3 data map and plots ..." - Please either 1.) describe the patterns that you see in your city of interest and if there are any correlations to industries or transportation corridors; or 2.) how are CO<sub>2</sub> concentrations varying for different months or years and what could be the cause? (This is a bonus question.)