

Problem Set #2 10 points Due Tuesday October 20, 2026

1. (1 pt) *Orbits* An orbit may be defined as occurring when $\vec{g}_{eff} = \vec{\nabla}(\Phi_g + \Phi_c) = 0$, where the gravitational and centripetal potential functions are $\Phi_g = G M/r$ and $\Phi_c = \Omega^2 r^2/2$. Solve for the distances r from the center of the earth for an object going around a) once every 23 hr 56 min (sidereal day) and b) once every 27.3 days.

2. (1.5 pts) *Circulation and vorticity*

a) What is the circulation about a circle of radius 500 km for a cyclonic vortex in the Northern Hemisphere, where the tangential wind speed increases outward at 10 m/s per 100 km?

b) What is the relative vorticity within the circle?

c) Evaluate the vorticity of the earth itself near the north pole, using the same method for a circle of radius 500 km centered at the north pole, assuming that the earth is in solid body rotation and the angular frequency is $\Omega = 7.292 \times 10^{-5} \text{ s}^{-1}$.

3. (1.5 pt) *Thickness*

a) Estimate the 1000-500 hPa thickness for an atmosphere with constant lapse rate 6.5 K/km and surface temperature $T_o = 273 \text{ K}$.

b) Examine a 1000-500 hPa thickness chart from a weather analysis or numerical forecast, such as a “surface” chart from the NCEP NAM model, at <http://www.aos.wisc.edu/weather/Models>. The dashed yellow contours are labeled in decameters (multiply by 10 to get thickness in meters). Estimate the mean 1000-500 hPa thickness across the contiguous 48 states. Using this, estimate the magnitude of a typical thickness anomaly (departure from the mean).

4. (1.5 pts) *Geostrophic wind*

a) Estimate the geostrophic wind at 4 km over Tateno Japan in Fig. 2 of the article about Ooishi and b) compare with the radiosonde observations in Fig. 9 (1° latitude = 111 km).

5. (1 pt) *Thermal wind*

Surface winds are calm in Madison, but temperatures in the lower troposphere are observed to increase eastward at 1 K per 100 km. Estimate the wind speed and direction over Madison at 5 km altitude if the surface temperature is 290 K and the lapse rate is adiabatic.

6. (2.5 pts) *Plotting zonal mean temperature and zonal wind using PANOPLY*

Please read “Panoply_readme.txt” and “Panoply_tips.pdf”, which include descriptions of how to add PANOPLY to your applications folder, tips on how to navigate the controls, and how to obtain data from NCAR’s research data archive. For this problem you can download the two ERA5 files of monthly mean temperature and zonal wind from the class website.

a) Use PANOPLY to make meridional cross-sections of monthly mean ERA5 zonal wind and temperature for the domain $90^{\circ}\text{S} - 90^{\circ}\text{N}$, 1000 hPa – 1 hPa for the year 2021. Please print them on one page and include it with your assignment.

b) On the two zonal wind cross sections label the subtropical westerly jets (SWJs), polar night jets (PNJs), and subtropical easterly jets (SEJs) in both hemispheres.

c) Using the thermal wind concept, briefly describe how the major cold and warm regions in the temperature cross sections are related to the SWJ. Why does the SWJ decrease in strength above the tropopause?

7. (1 pt) *Rotating tank.* Considering the radial acceleration of fluid elements accomplished by the height gradient, derive a formula for the dependence of depth, h , on radius, r , for an incompressible fluid in solid-body rotation at angular frequency Ω in a cylindrical tank with a flat bottom and free surface. Let H be the depth at the center of the tank.

PANOPLY TIPS

Open PANOPLY and then open a file such as

e5.moda.an.pl.128_130_t.ll025sc.2021010100_2021120100

Double click on U_component Geo2D in the menu

From here you can choose from many different kind of plots. For each different type of plot you will usually need to start again by opening the data file. To make a meridional section click on “Color contour plot”, choosing lat for x axis and isobaric for y axis. Click on create.

In the PANOPLY tool bar under Window click on Plot Controls, where you can select from the following menu:

arrays – choose month 1 – 12

contours – default is fine

grid – customize your grid so that it spans -90 to 90 and 1000 to 1 hPa with log coordinate; to get the x axis labelled nicely you could try %.0f font and begin with major 2, minor 2, then change major to 18

labels – add a label at the top such as ERA 5 monthly mean temperature; July 2021

layout – default is fine

scale – play with min and max range and with major and minor ticks; it often works well to use multiples of 6 or 12 for the range, such as -120, 120 for U, with 12 and 2 for ticks

vectors – if you open two velocity component files you could use this function

Obtaining data from NCAR’S Research Data Archive

You might like to explore other years of ERA5 data or other data sets.

Navigate to rda.ucar.edu in your browser. Search and click on a data set such as

ERA 5 monthly means ds633.5 (PANOPLY can use GRIB1 or NETCDF)

Click on the web file listing

Choose date and variable

If you click on a filename it will download to your computer, probably to downloads

If you want to click on many files you may want to prompt rda to make a script. To do so click on CREATE unix script using Wget or Python.

Copy the generated script into a unix file using nedit or vi with a name such as script_era5,

make it executable with `chmod a+x script_era5`

then execute it in a terminal window with `./script_era5`

and it will automatically download lots of data files.

PANOPLY

panoply \PAN-uh-plee\, noun: 1. A splendid or impressive array. [...]

INTRODUCTION

Panoply is a Java application that allows the user to make plots of data from netCDF, HDF, and GRIB datasets. Although its strength is in making longitude-latitude (map) plots, it can also make other types of georeferenced plots, including keograms and Hovmoeller diagrams;

general 2D color contour plots; and line plots. Data arrays may be "sliced" from larger multidimensional arrays (aka, variables). A large selection of global map projections is available for lon-lat figures. Plot images may be saved to disk in bitmap graphic formats or in PDF.

Panoply requires that a Java 11 (or later) Runtime Environment be installed on your computer. Please read the accompanying JAVA_11 README file for details.

DOWNLOADING

The current version of Panoply, along with other information about the application, may always be found at

<https://www.giss.nasa.gov/tools/panoply/>

INSTALLING AND RUNNING THE PANOPLY FOR MAC OS PACKAGE

The complete Panoply package for macOS should, after uncompression, include the following items:

- Double-clickable Panoply application.
- This README file.
- A JAVA_11 README file.

To run Panoply on macOS, just double-click on the Panoply application.

TROUBLE-SHOOTING

There have been some reports that Panoply for macOS fails to launch on recent Macs built with "M1 silicon" ARM chips. Please see the JAVA_11.txt file accompanying this README for more info

and for possible workarounds.

Some users who have a second display attached to their Mac have reported Panoply does not respond after they select an input file via the filechooser dialog. If you experience this, please download and try the version labeled (JFC), which uses the Java filechooser.

OTHER DOCUMENTATION

More details about Panoply are available at:

<https://www.giss.nasa.gov/tools/panoply/>

COLOR TABLES AND CONTINENTS FILES

Beginning with version 4, Panoply's "standard" selection of color tables and map overlays is built into the application. Additional color tables and map overlays may be opened for a single session or added to your favorites library for continued use. See the Panoply website for for such optional support files.

CONTACT

Panoply was developed at the

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Please send bug reports, etc., to Dr. Robert Schmunk at robert.b.schmunk@nasa.gov.

ACKNOWLEDGMENTS

Panoply uses Java classes and libraries written by several third-party organizations. A complete list, with links to pertinent websites containing license information and source code, may be accessed via Panoply's Help menu or on the Panoply website.