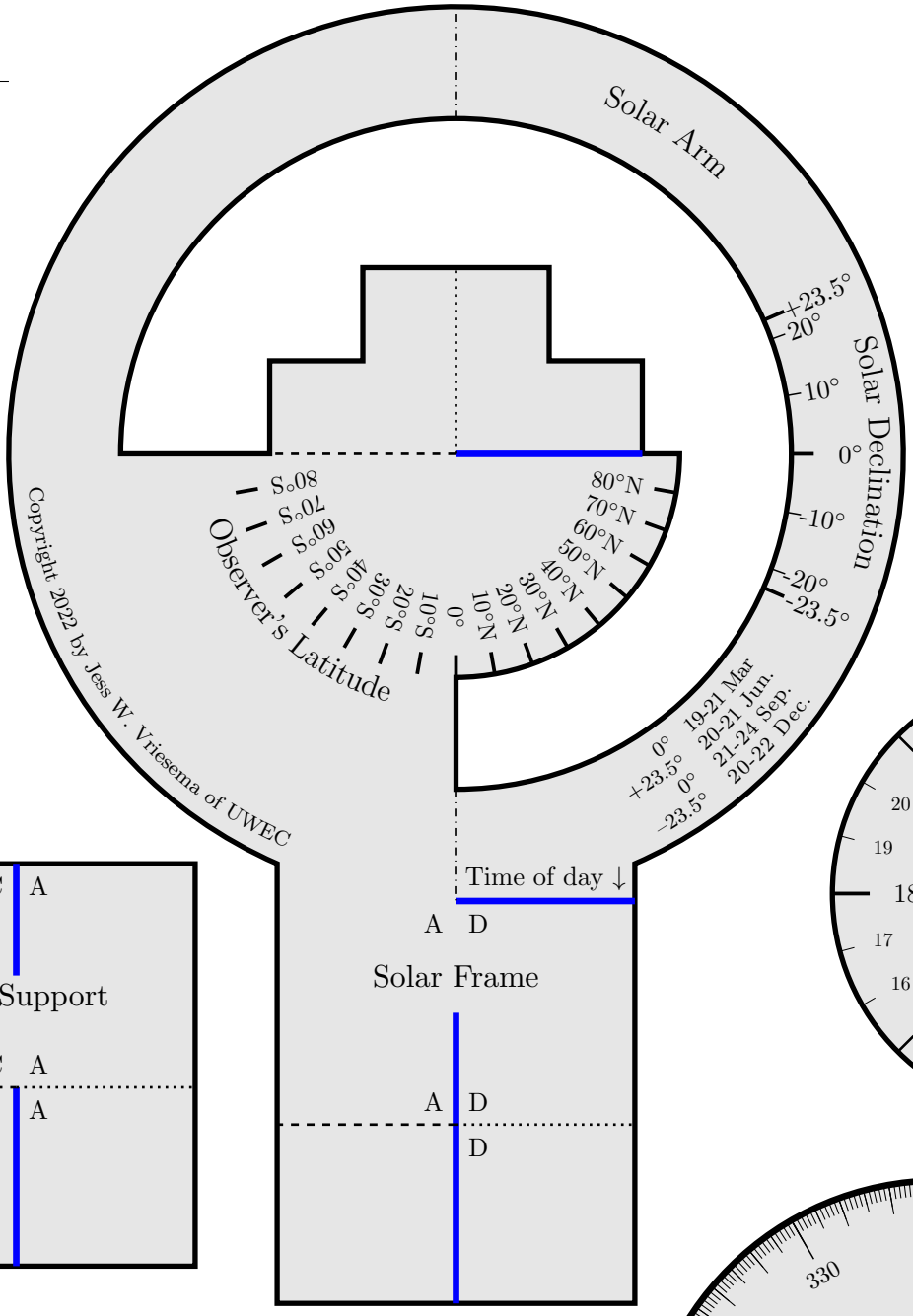
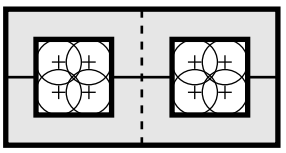
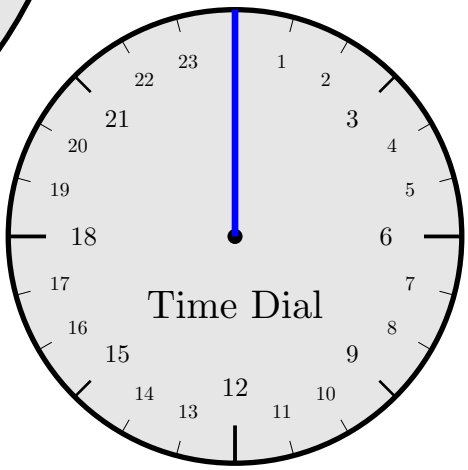
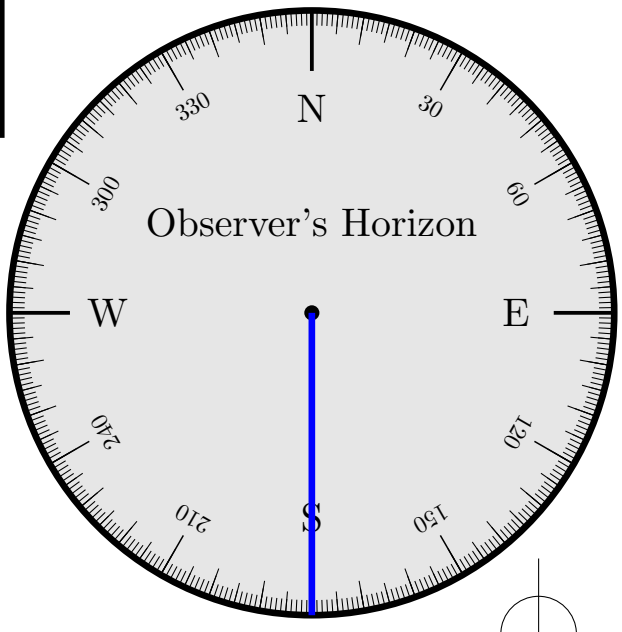






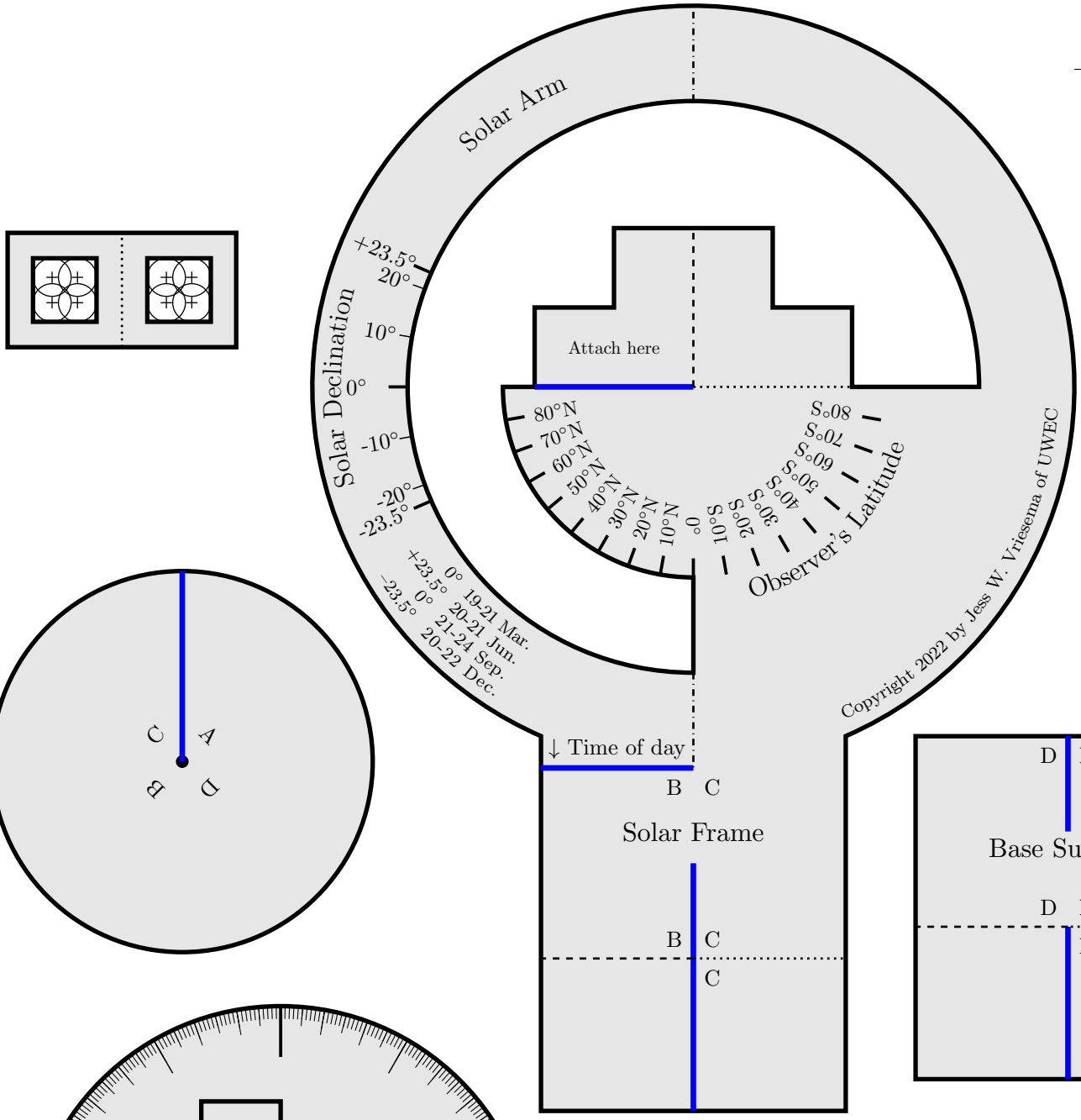


Adjust the Observer's Latitude
Rotate the Horizon Disk so that its southern edge points to the desired latitude on the "Observer's Latitude" track.

Adjusting the Time of Year
Move the Sun Slider to the appropriate declination marked on the Solar Arm. The solar declination is approximately +23.5° on/near June 20/21, -23.5° on/near December 21, and 0° at either equinox (March 19/20 or September 22/23).

Adjusting the Time of Day
Swivel the Solar Arm such that the "Time of day ↓" indicator at its base points to the desired time on the Time Dial.

Simulating the Sun's Daily Motion
The Sun Slider represents the Sun. You can simulate the position of the Sun over the course of a day by pivoting the Solar Arm from 0 (midnight) to 6 (6 AM) to 12 (noon) to 18 (6 PM) to 24 (midnight). Sunrise happens when the Sun Slider crosses from behind the Horizon Disk (usually in the eastern sky) in the morning. Sunset happens when the Sun Slider crosses from above the Horizon Disk to below it (usually in the western sky) in the evening. Some people find it helpful to rotate the entire model such that the printed Horizon Disk faces up.



Videos including an introduction, assembly instructions and examples, will be available at https://youtube.com/playlist?list=PL4fXsHwnHJ0unhdGVK-Qs-AM1HSjOCj5C.

For more information, please visit https://www.lpl.arizona.edu/~vriesema/solar_motion.html.

Feel free to contact me with questions, comments or suggestions.
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Twitter: https://twitter.com/Jvriesem

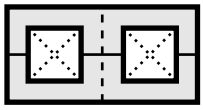
Instructions

Print the first two pages of this document (front and back) on a single piece of letter-sized (8.5 inches by 11 inches) cardstock. Be sure to align the front and back designs as closely as possible.

1 Cutting out pieces

First, cut out the Time Dial and Horizon Disk as well as the rectangular Base Support. Cut out the outline of the Solar Frame, then carefully cut out its interior.

BEFORE cutting out the small rectangle with two smaller rectangles, cut out the smaller rectangles first. This is the most difficult step. It can be helpful to use a pen/pencil to pierce the center of the interior rectangles, then carefully cut a × shape from each corner to the center, as is shown below.



Then, you can lift each triangular flap and cut it out separately. Alternatively, you may use a hole punch using the marks shown to approximately cut out the interior. Once the interior regions are removed, you can carefully cut out the outer rectangular shape.

2 Incisions

Make an incision along the thick lines on the Horizon Disk and Time Dial. For the Horizon Disk, this is from the center to due south. For the Time Dial, this is from the center to the zero or 24-hour position. Next, make three incisions on the Solar Frame along the three thick, dark lines: one from the bottom (near its feet), one below "Time of day ↓", and the other above the 80°N latitude line. Finally, make the two indicated incisions on the Base Support. If printed on cardstock, make the cuts *slightly* wider to accommodate the thickness of the paper.

3 Folds

The different dotted/dashed lines have the following meanings:

- Dotted → valley fold (the printed dotted line is in the inside of the fold)
- Dashed → mountain fold (the printed dashed line is in the outside of the fold)
- Dashed and dotted → fold both ways (it will need to go both ways)

4 Assembly

4.1 Horizon Disk

Temporarily un-fold the center two folds in the Solar Frame (largest piece) and flip it over. Slip the Horizon Disk's incision into the incision in the middle of the Solar Frame such that the support flaps in the middle of the Solar Frame are on top of the Horizon Disk and the degree markings on the Horizon Disk are face-down. Line up the "Attach here" bits on the support flap and Horizon Disk, then affix the support flaps using tape. Rotate the horizon disk so that its "south" incision slides along the "Observer's Latitude" track. It should be loose enough to move easily but tight enough to hold its position when left untouched.

4.2 Sun Slider

Place the folded Sun Slider onto the frame near the solar declination label, such that half of the slider is in front of the Solar Arm and half is behind it. Then, use a small piece of tape to make the Sun Slider into a sleeve around the Solar Arm. (Be careful not to tape the sleeve to the arm!) The slider should be able to slide to different solar declination values. It should be a snug fit: loose enough that your hand can move it, but tight enough that it stays put when you are not touching it.

4.3 Base Support

Slip the incision furthest from the folds on the base support onto the bottom of the frame, near the folds. The folded feet will be arranged in a windmill pattern for support. If done correctly, six of each letter (A, B, C and D) will be grouped together. Strongly recommended: for added stability, you can tape the feet onto the nearby legs.

4.4 Time Dial

Slip the Time Dial onto the neck of the Solar Frame. The slit in the Time Dial should line up with the slit on the Solar Frame pointed to by the "Time of day ↓" indicator, and the printed side should be facing up.

5 How to Use

5.1 Adjust the Viewing Latitude

The latitude of the observer can be adjusted by rotating the horizon disk. The southern edge of the horizon disk will point to the observer's latitude on the "Observer's Latitude" track.

5.2 Adjusting the Time of Year

At different times of the year, Earth's tilt causes the Sun to appear more north or more south of the celestial equator (0° declination). Move the Sun slider to the appropriate declination. The solar declination is approximately +23.5° on/near June 20/21, -23.5° on/near December 21, and 0° at either equinox (March 19/20 or September 22/23).

5.3 Adjusting the Time of Day

The solar arm (labelled "Solar Declination") acts like a hinge. Its position indicates the rotation of the Earth — or equivalently, the time of day. The solar arm has an indicator at the bottom which points to the time of day on the time dial. For example, at 6 AM the solar arm will be aligned with E (east) on the horizon disk and 6 on the time dial.

5.4 Simulating the Sun's Daily Motion

You can simulate the position of the Sun in the sky by pivoting the Solar Arm from 0 (midnight) to 6 (6 AM) to 12 (noon) to 18 (6 PM) to 24 (midnight). The Sun slider represents the Sun. Sunrise happens when the Sun slider crosses from behind the horizon disk (usually in the eastern sky) in the morning. Sunset happens when the Sun slider crosses from above the horizon disk to below it (usually in the western sky) in the evening. Some people find it helpful to rotate the entire model such that the printed Horizon Disk faces up.

To Do List

The following are things that should be done when I have time. Chores.

- Add dates to Solar Arm? (Maybe at bottom?) Make switch for this so educators can decide how many clues to give students.
- Add compass markings for solar declination beyond the Sun's extent, but highlight the real ones?
- Add "Observer's Latitude" indicator arrow on the Horizon Disk, as with the Time Disk and Solar Arm.
- Make a version with AM/PM times instead of 24-hour time. Adjust instructions accordingly.
- Figure out a way to easily adjust the friction between Solar Carriage and Solar Arm.
- Revise the instruction card and instructions to use less jingo.
- Clarify the license terms somewhere?
- Move the "S" off-axis somewhat, since it gets sliced in two otherwise?
- Draw cardinal points on the back of the horizon disk?
- The angles in the Solar Frame need some adjustment. Note the pgfsetmacro commands to account for the outline width thickness and such. The stuff in the asin() functions is only approximate right now. That needs to be done for the laser cut things, too.
- Make the horizon disk's support flap have a shape that has a unique orientation.
- Typeset the URLs better: href vs. url?
- Adjust the "Base Support" and "Solar Frame" labels and their kin.
- Improve instructions:
  - Update instructions for how the horizon disk should be when taped onto the solar frame. This was frustrating for me (the designer!) this past time.
  - Organize better?
  - Add introduction?
  - Add space to the instruction card to affix the base?

Wishlist

The following are things I'd love to do when I have some creative inspiration. Non-necessary.

- Figure out a way to attach the base support and solar frame without tape (e.g. inserting a paper slip into a slit).
- Give friction to sliders
  - Make the central latitude angle indicator and Solar Arm (near Solar Slider) edge be more of a small-scale (0.5mm?) square wave — at least when laser cutting. Then, students could fold the tiny flaps in or out, which would provide some friction against whatever was sliding.
- Make a more advanced version for advanced students:
  - Discuss the analemma or Equation of Time?
    - Add a mini analemma to the solar arm to show dates? (If so, I might need to thicken the solar arm in order to fit the text in there.)
  - Adjust to calculate earliest/latest sunset times, WHICH ARE NOT SOLSTICES. See "Earliest and latest sunrise and sunset" for info.
- Make good use of the backside of the instruction card?
  - Add a diagram or pic of the finished product?
  - Add brief assembly instructions?
  - Add a QR code for downloading this thing?
  - Determine a clever way to put a copyright symbol on the printed material somewhere.
- Have a star in or outside of the Solar Carriage?
- Determine the best way to perforate folds with laser cutter:

  - What is an ideal perforation: dashed? dotted? solid line through middle?

- Create an activity or two to go with this:
  - One version for younger students, one for university students?
  - Things to include (following Revised Bloom's Taxonomy):
    * Remember / Recall (understand how to use the model by recalling directions)
      · What does moving the "Solar Arm" simulate?
      · How can you change the observer's latitude?
      · How can you change the time of day?
      · How can you change the time of year?
    * Understand / Explain
      · If the Horizon Disk is rotated such that "N" is at the top and "S" is toward the base, what latitude does this correspond to?
    * Apply / Use Information
      · Find a date when the Sun is highest/lowest in the sky at your latitude.
      · Does the Sun always rise in the east and set in the west?
      · What time does the Sun rise and set today at your latitude?
      · What time of year is the Sun the highest/lowest in the sky at your latitude?
      · What time is the Sun highest in the sky?
      · What time of year has the longest/shortest length of day at your latitude?
      · Find a latitude and time of year such that the Sun never sets or rises.
      · Find a latitude at which the Sun is directly overhead on a given date.
      · Predict/calculate sunrise times as a function of latitude and time of day.
    * Analyze / Draw Connections
      · How does the sunrise/sunset *time* change with the time of year?
      · How does the length of day change with the time of year?
      · How does the sunrise/sunset *location* change with the time of year?
      · How does the length of day change with the time of year?
      · Is the Sun highest in the sky at the same location (azimuth) for different times of the year? (Reword)
      · Predict/calculate critical latitudes (arctic/antarctic circles, tropics).
    * Evaluate
      · This model works if the time is understood as local solar time. How would this model change depending on a person's east/west location within their timezone?
      · What are some limitations of this model?
      · This model does not account for the analemma. What differences are there in this model?
    * Create
      · Based on this model, explain how the Sun causes the seasons.
      · Use this model to explain what would be different if the Earth were tilted at 40° instead of 23.5° (solar motions, seasons, temperatures, etc.).