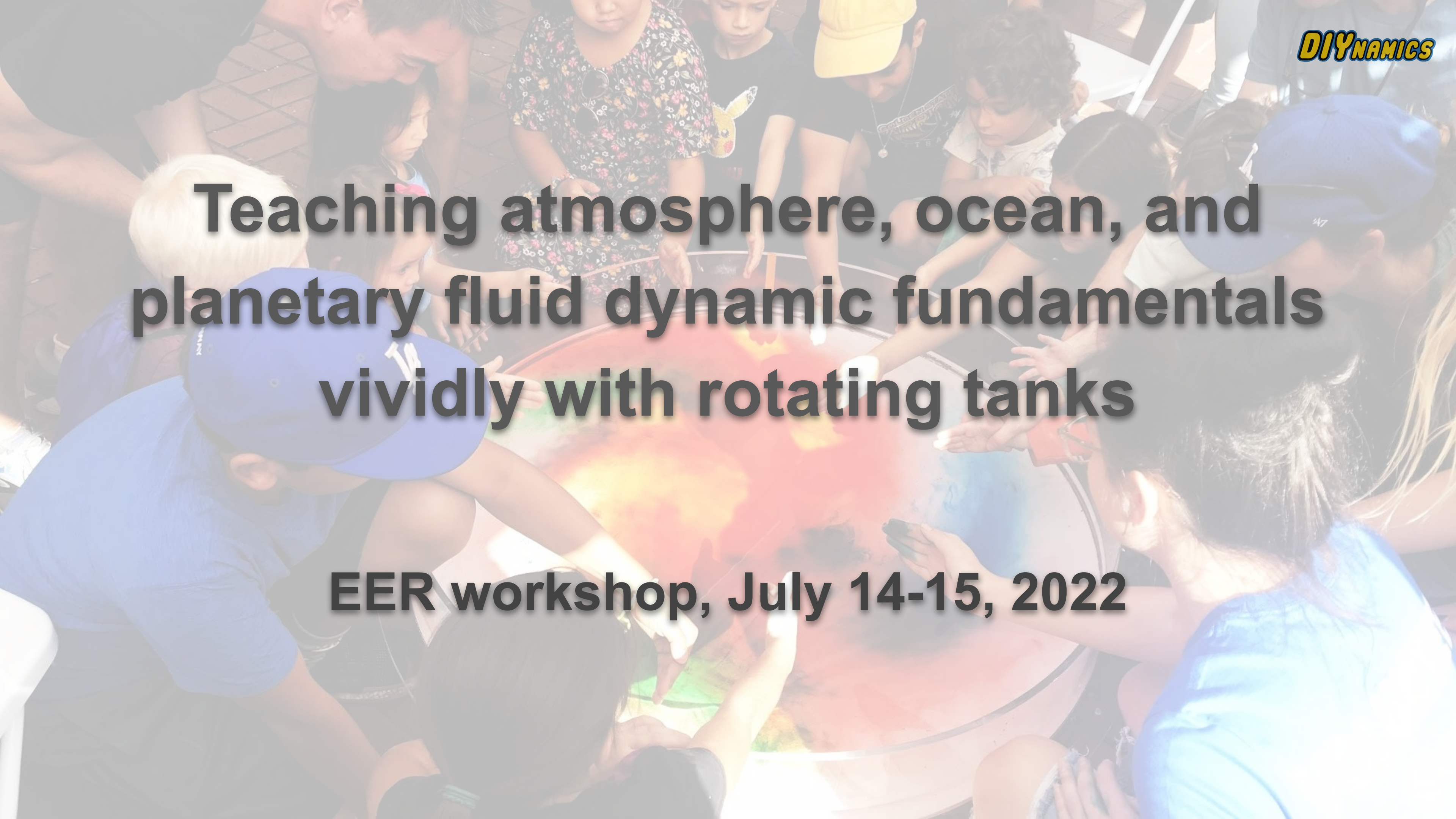


DIYnamics

Teaching atmosphere, ocean, and planetary fluid dynamic fundamentals vividly with rotating tanks

EER workshop, July 14-15, 2022

Welcome! Who are we?

Do-It-Yourself dynamics! A diverse group of rotating tank enthusiasts, from students to professors, coast to coast

https://diynamics.github.io/

Welcome! Who are we?

Spencer Hill	Princeton	monsoons, Hadley cells
Jon Aurnou	UCLA	planetary dynamos
Indrani Ganguly	Iowa State University	tropical atmosphere
Alex Gonzalez	Woods Hole	tropical atmosphere
Norris Khoo	rotating tanks enthusiast	tank engineering, videos
Juan Lora	Yale	planetary atmospheres
Jordyn Moscoso	UCLA/USC/UCSC	oceanography

Who supports us?

Princeton University Cooperative Institute for Modeling the Earth System ($)

National Science Foundation ($)

NASA ($)

SERC

The nice people in the lab down the hall

Who you all are…a wonderfully diverse group!

Based on our pre-workshop survey:

65% at 4-year college, 25% at 2-year college, 10% at K-12

15% new to atmosphere/ocean/planetary science
Welcome! We're glad to have you here

60% are new to rotating tanks
25% are new to teaching with rotating tanks

More science later…for now, let's build the kits!

Everyone gets a DIYnamics Technics rotating tank!
Assembly instructions printouts are on the tables

Pair up with people near you
Introduce yourselves, share printouts,
help each other troubleshoot

Once motor assembled and successfully turns on/off
(green button), raise your hand and we'll fill your tank

Then turn back on motor and get your tank spinning
Voila! A fully functional rotating tank platform

Our first two demos!

Join us at the big table, the “HT3”, for a tutorial led by Jordyn

Solid body rotation and mechanical stirring

After: try this experiment out for yourself!

Pair up with someone you haven’t met yet

Discuss your observations w/ each other

Contrast w/ identical demos but for tank that’s not rotating

We’ve placed a few non-rotating tanks around the tables

Finally, the science

Now: ~45 min presentation on the underlying scientific concepts
And how a Lazy Susan is useful for understanding the Earth

Four key concepts:

1. From a spherical planet to a flat tank
2. Fluids = both gases and liquids
3. From a giant planet to a small tank
4. Fluid flows on our spinning Earth

(After that: 5 min break)

Finally, the science

Emphasis in this workshop is on gaining *experiential* knowledge of atmospheric, oceanic, and planetary flows

To literally get a *feel* for them

Alas, at the expense of theoretical precision

Handouts you'll take home include both conceptual and hardcore explanations

Geophysical Fluid Dynamics

-**Geo:**

Earth (or another **rotating** planet)

-**physical**:

Relating to the branch of science called “physics”, which is the study of how real-life objects in our universe behave

-**fluid**:

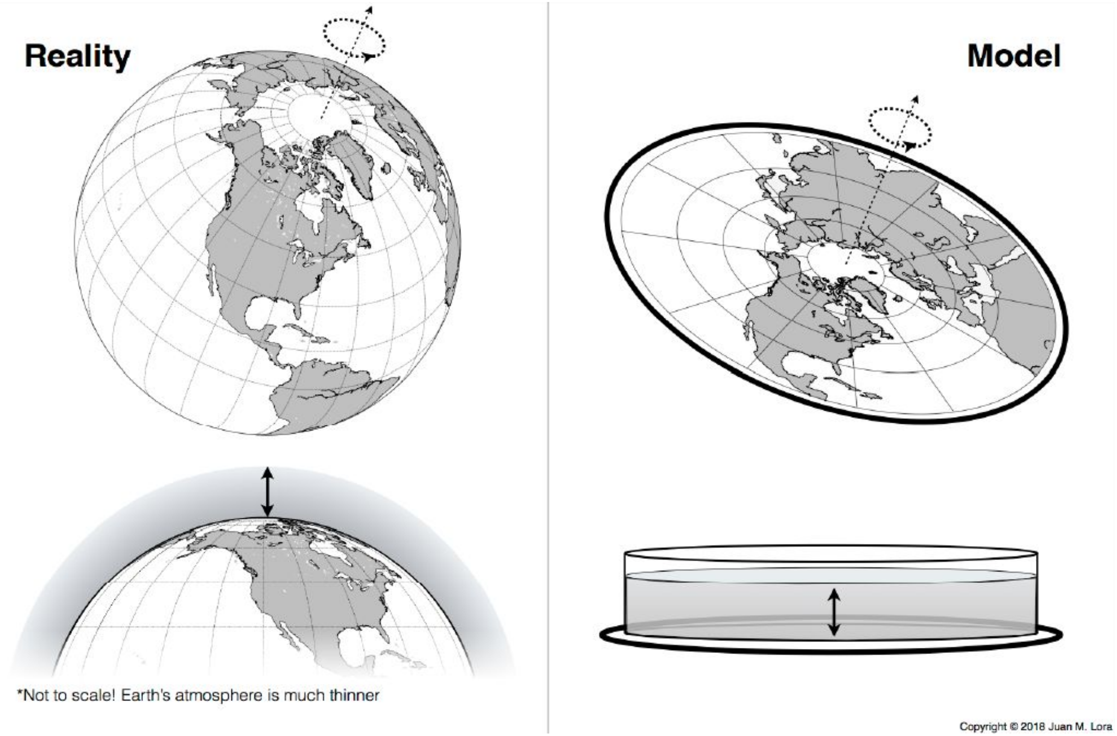
any gas (like the atmosphere) or liquid (like the ocean or molten metal in Earth’s core)

-**dynamics**:

how things move around

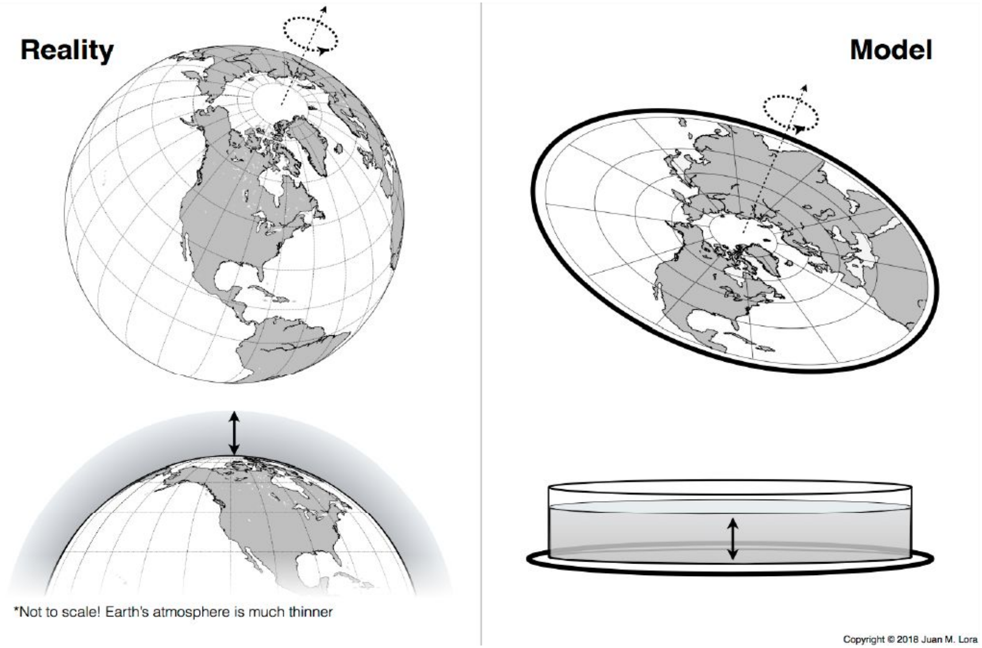
Together then, geophysical fluid dynamics refers to the behavior of moving fluids on a rotating planet.

What does our model capture about the natural world?



- We model **geophysical fluid dynamics** using a rotating tank of water.
- The tank represents the planet, and the water in the tank represents the atmosphere (or the ocean, or the planet's core).

How do we model these fluids?

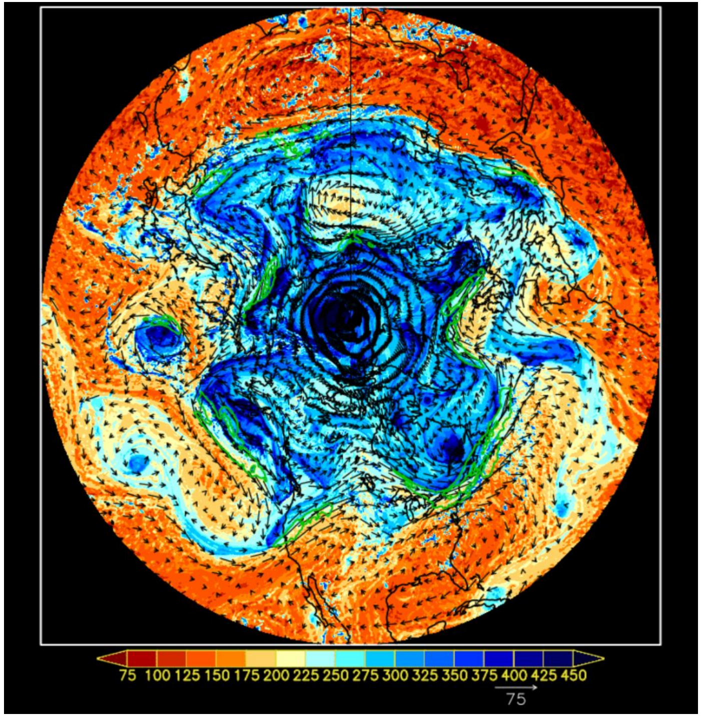


1. The earth's radius is approximately 6370 km. what is the horizontal scale of out tank model? 17.5 cm!

2. The depth of the **troposphere**, the part of the atmosphere where weather happens, is roughly 10 km. What is that analogous to in our model? ~7.5 cm!

The major difference between our model and the real world is scale, or the representation of size.

Going from the Earth to a tank!



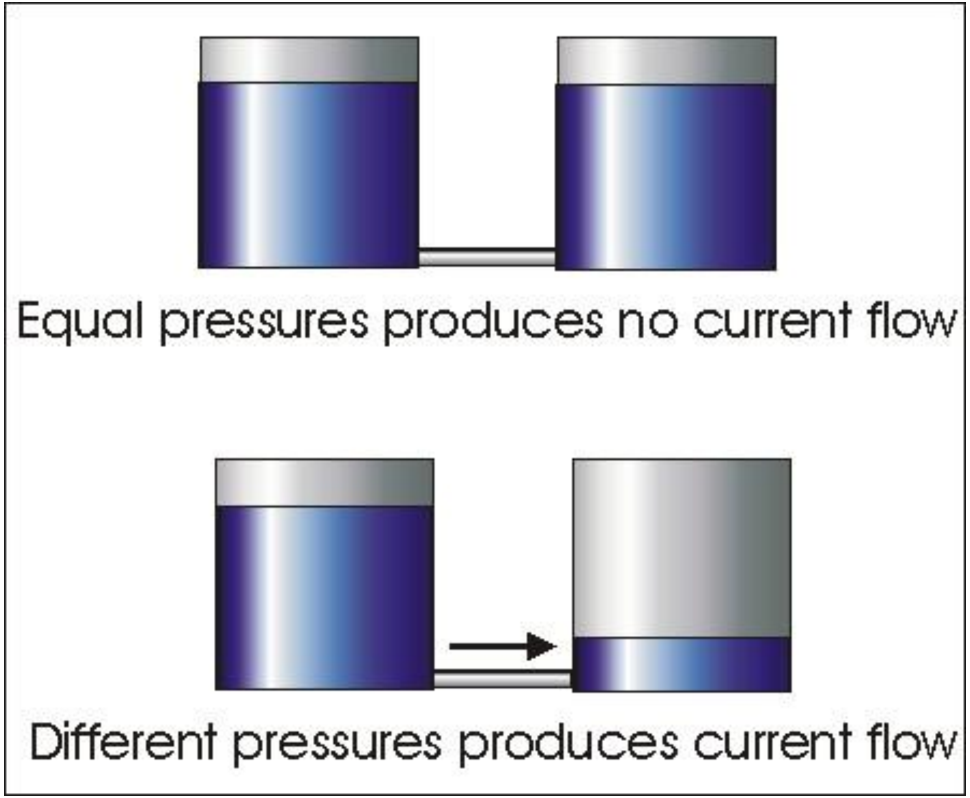
Questions?

Fluids: Is water really a good analog for the atmosphere?

In physics,

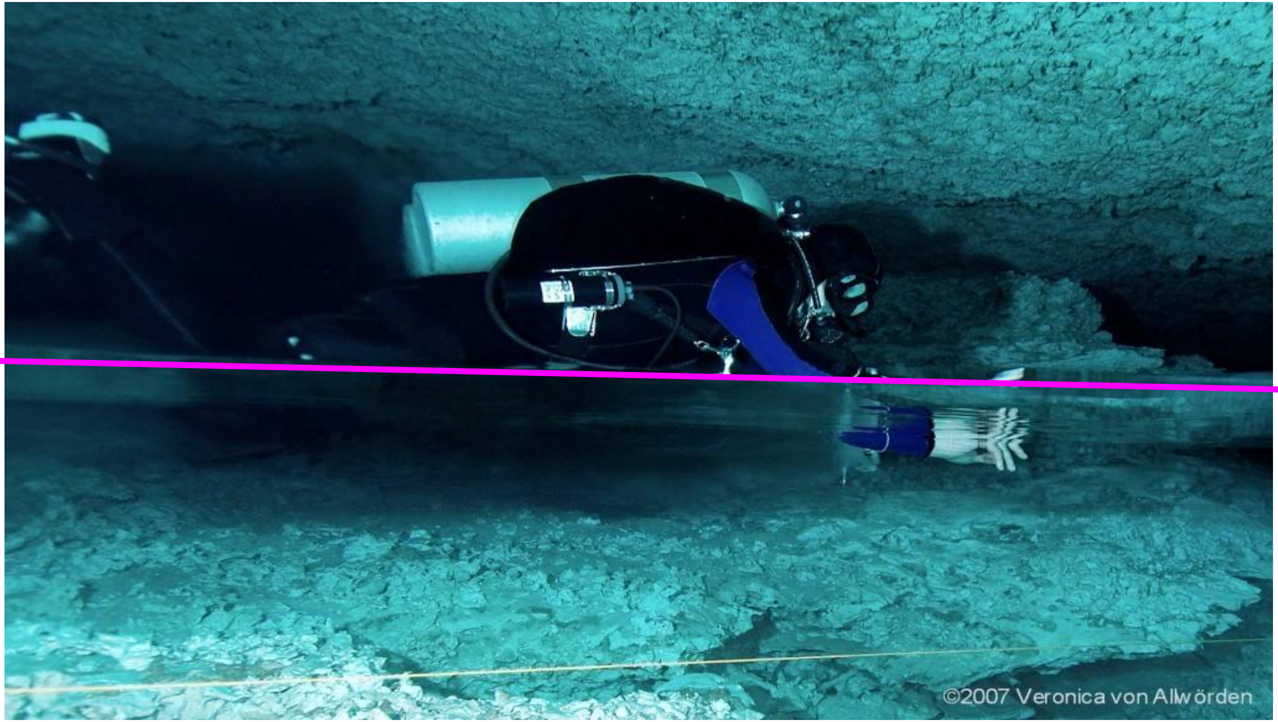
fluid = a substance that has no fixed shape and yields easily to external pressure; a gas or a liquid.

Both the atmosphere and ocean respond to pressure



Density is important in the atmosphere and ocean

Lighter fluid



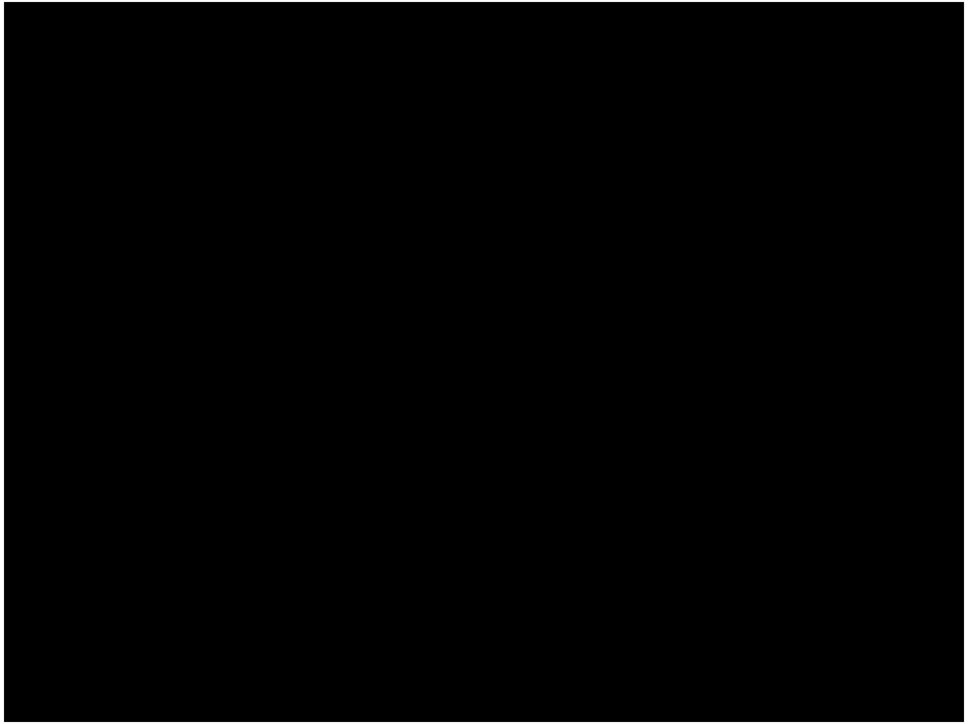
Denser fluid

Density is important in water and air

Example: convection

Atmospheric convection: on sunny days, air warmed by the surface rises

Oceanic convection: in winter, salty surface ocean water sinks



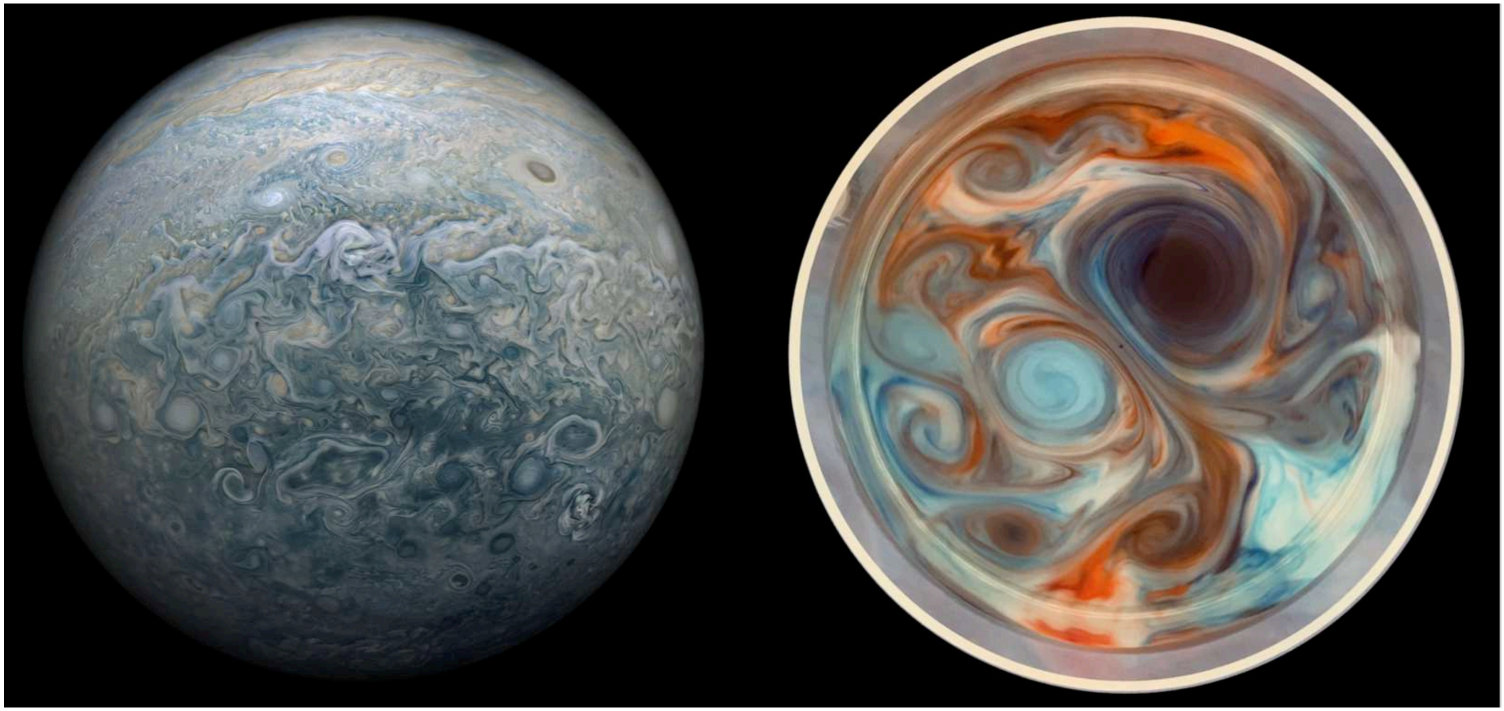
Water and air are fluids

The flow of fresh water in a tank, salty water in the ocean, and air in the atmosphere responds to the same forces!

This includes forces associated with rotation

Questions?

Scale Modeling of Geophysical Flows *aka "How can that little tank act like a planet?"*



Jon Aurnou (aurnou@g.ucla.edu)

Scale Modeling

- **Goal:** Create similar dynamics in tanks as occurs on planets
- **Recipe**:
  - **Physics:** Shortest time scale processes dominate (e.g., largest accelerations)
    - **Estimate** two shortest **time scales**
      - **Take their ratio** (e.g., quantifies their relative import)
        - Between planet & tank, **match their respective ratios**

Ratio of Time Scales

- **Goal:** Create similar dynamics in tanks as occurs on planets
- **Estimate**
    - The **rotation time** scale T_{Ω}
    - And the **flow time** scale T_{flow}

Ratio of Time Scales

- **Goal:** Create similar dynamics in tanks as occurs on planets
- **Estimate**
  - The **rotation time** scale $T_\Omega \simeq \dfrac{1}{2\Omega}$
  - And the **flow time** scale T_{flow}

Ratio of Time Scales

- **Goal:** Create similar dynamics in tanks as occurs on planets
- **Estimate**
  - The **rotation time** scale $T_\Omega \simeq \dfrac{1}{2\Omega} \ \left(= 86400/(4\pi) \ s\right)$
  - And the **flow time** scale T_{flow}

Ratio of Time Scales

- **Goal:** Create similar dynamics in tanks as occurs on planets
- **Estimate**
  - The **rotation time** scale $T_\Omega \simeq \dfrac{1}{2\Omega} \ \left(= 86400/(4\pi)\ s \right)$
  - And the **flow time** scale $T_{flow} = \dfrac{flow\ length}{flow\ velocity} = \dfrac{L}{V}$

Ratio of Time Scales

- **Goal:** Create similar dynamics in tanks as occurs on planets
- **Estimate**
  - The **rotation time** scale $T_\Omega \simeq \dfrac{1}{2\Omega} \;\left(= 86400/(4\pi)\ s\right)$
  - And the **flow time** scale $T_{flow} = \dfrac{flow\ length}{flow\ velocity} = \dfrac{L}{V}$
  - **Time scale ratio:** $\dfrac{T_\Omega}{T_{flow}} = \dfrac{V}{2\Omega\, L}$

Ratio of Time Scales

- **Goal:** Create similar dynamics in tanks as occurs on planets
- **Estimate**
  - The **rotation time** scale $T_\Omega \simeq \dfrac{1}{2\Omega} \;\left(= 86400/(4\pi)\ s\right)$
  - And the **flow time** scale $T_{flow} = \dfrac{flow\ length}{flow\ velocity} = \dfrac{L}{V}$
  - **Time scale ratio:** $\dfrac{T_\Omega}{T_{flow}} = \dfrac{V}{2\Omega\, L}$ ← Match value in experiments to planets

Ratio of Time Scales

- **Physics:** Shortest time scale dominates (e.g., largest acceleration)
- **For flows on planetary-scales, $L \sim R_P$:**
  - $T_\Omega \ll T_{flow}$

Ratio of Time Scales

- **Physics:** Shortest time scale dominates (e.g., largest acceleration)
- **For flows on planetary-scales, $L \sim R_P$:**
  - $T_\Omega \ll T_{flow} \quad \longrightarrow \quad \dfrac{T_\Omega}{T_{flow}} = \dfrac{V}{2\Omega R_P} \lesssim 1$

Ratio of Time Scales

- **Physics:** Shortest time scale dominates (e.g., largest acceleration)
- **For flows on planetary-scales, $L \sim R_P$:**
  - $T_\Omega \ll T_{flow} \quad \longrightarrow \quad \dfrac{T_\Omega}{T_{flow}} = \dfrac{V}{2\Omega R_P} \lesssim 1$
    - Rotation (Coriolis!!!) dominates multi-day planetary-scale flows

Ratio of Time Scales

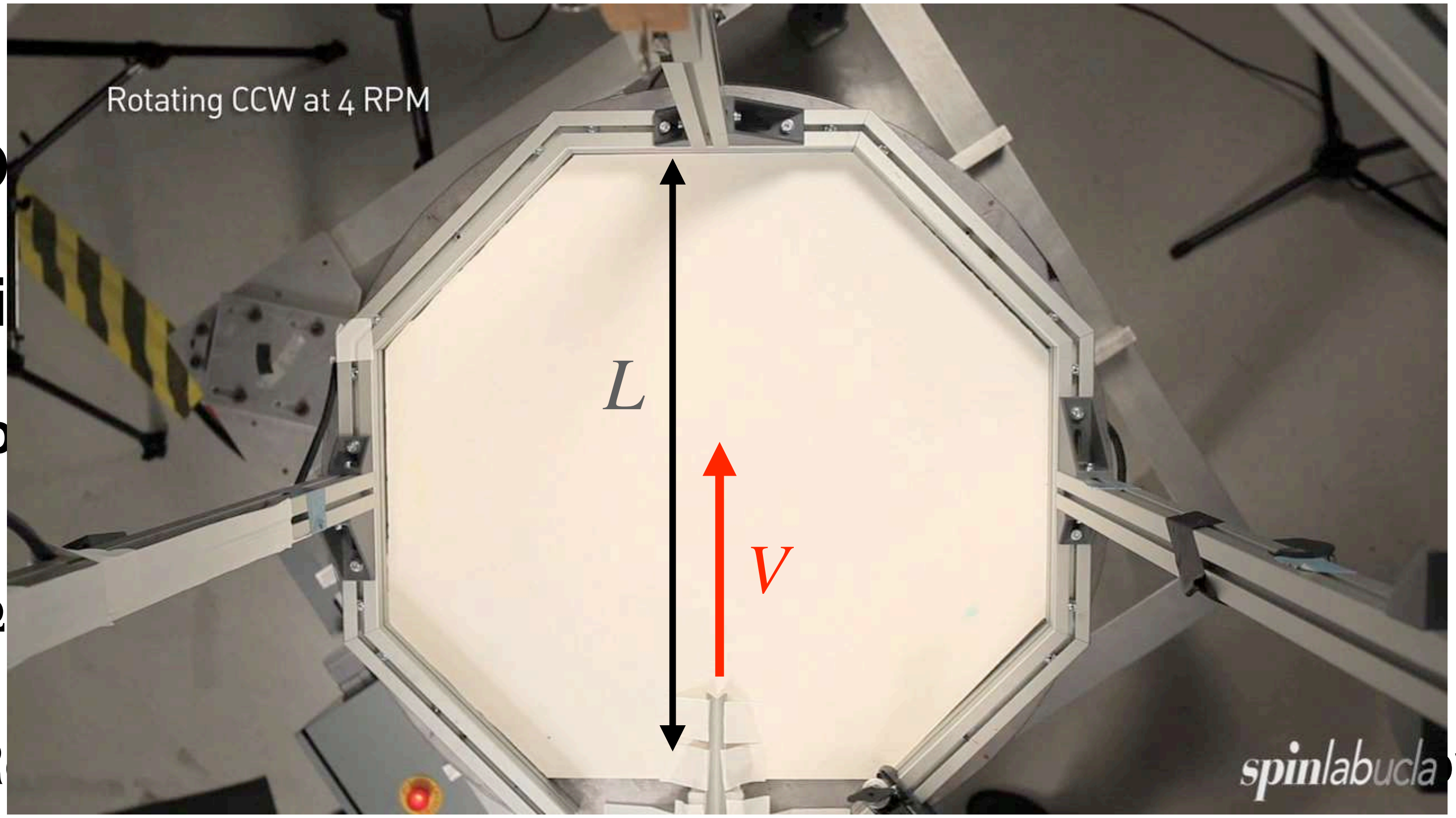
- **Physics:** Shortest time scale dominates (e.g., largest acceleration)
- **For flows on planetary-scales,** $L \sim R_P$**:**
    - $T_\Omega \ll T_{flow} \quad \longrightarrow \quad \dfrac{T_\Omega}{T_{flow}} = \dfrac{V}{2\Omega\, R_P} \lesssim 1$
    - Rotation (Coriolis!!!) dominates multi-day planetary-scale flows
        - Gedanken Time Scales Expt (Coriolis)

Ratio

- **Physi**
- **For flo**

  - T_Ω

  - R ws



- Gedanken Time Scales Expt (Coriolis)
- SpinLab Time scales Movie (Coriolis!)

Ratio of Time Scales

- **Physics:** Shortest time scale dominates (e.g., largest acceleration)
- **For flows on planetary-scales, $L \sim R_P$:**
- $T_\Omega \ll T_{flow} \quad \longrightarrow \quad \dfrac{T_\Omega}{T_{flow}} = \dfrac{V}{2\Omega\, R_P} \lesssim 1$
  - Rotation (*Coriolis!!!*) dominates multi-day planetary-scale flows
    - Gedanken Time Scales Expt (Coriolis)
    - SpinLab Time scales Movie (Coriolis!)
    - Ball in a Bowl (Coriolis!!)

Ball in a Bowl

- Roll ball inside a bowl, nearly(*!*) circling at angular velocity $\approx \Omega$

Ball in a Bowl

- **Roll ball inside a bowl, nearly(*!*) circling at angular velocity $\approx \Omega$**

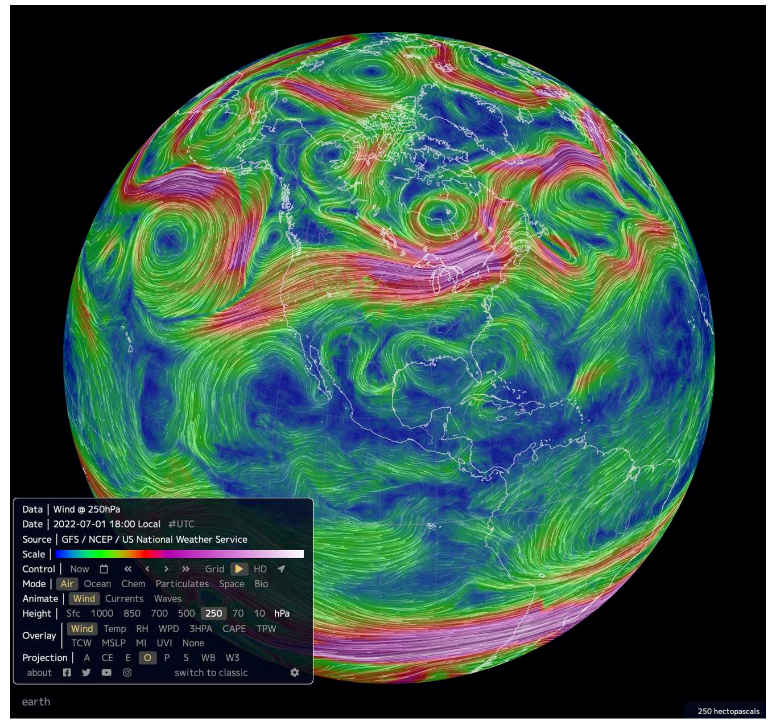
- RHS: digitally transformed into Ω-frame
  - diyrot.epss.ucla.edu
- Coriolis deflects ball into circles: $R = V/(2\Omega)$
  - $d\vec{V}/dt = \vec{V} \times 2\vec{\Omega}$
  - V in Ω-frame
  - $T_{circles} = \frac{1}{2\Omega}$

Ratio of Time Scales

- **Physics:** Shortest time scale dominates (e.g., largest acceleration)
- **For flows on planetary-scales, $L \sim R_P$:**
  - $T_\Omega \ll T_{flow} \quad \longrightarrow \quad \dfrac{T_\Omega}{T_{flow}} = \dfrac{V}{2\Omega\, R_P} \lesssim 1$
    - Rotation (*Coriolis!!!*) dominates multi-day planetary-scale flows

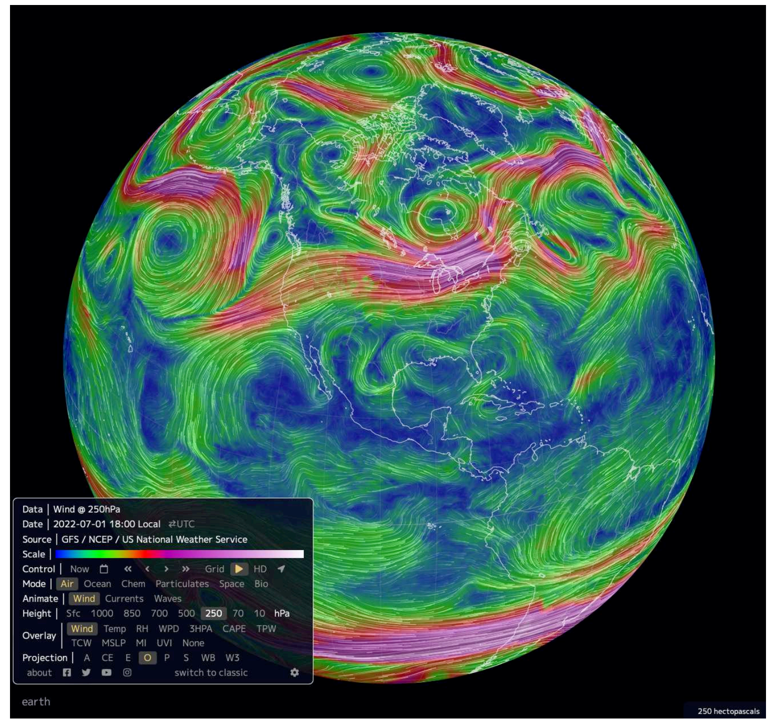
Match Their Ratios

- **Atmospheric flow** (at $z \simeq 10$ km):
  - $V \simeq 100$ m/s; $R_P \simeq 6370$ km
  - $T_\Omega / T_{flow} \simeq 0.11$



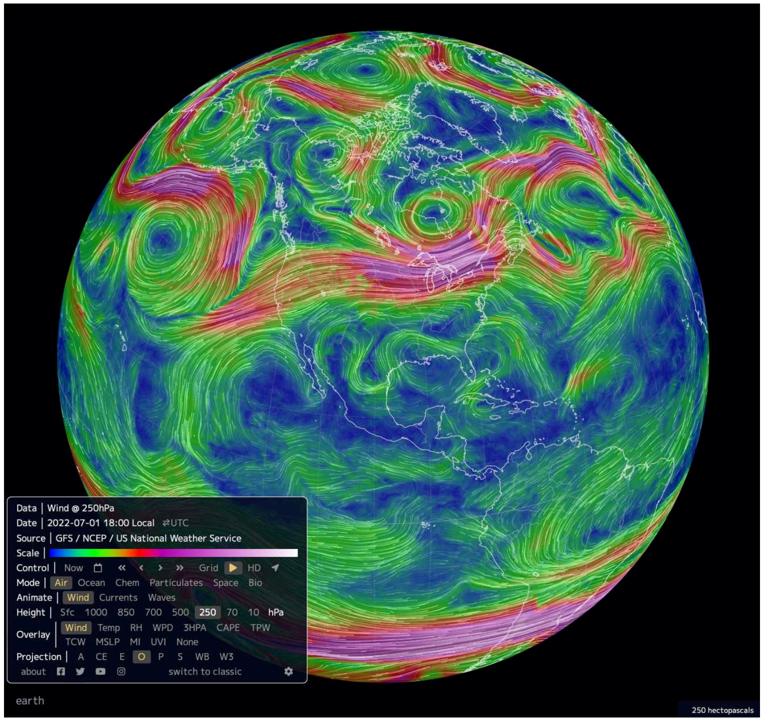
Match Their Ratios

- **Atmospheric flow** (at $z \simeq 10$ km):
  - $V \simeq 100$ m/s; $R_P \simeq 6370$ km
  - $T_\Omega / T_{flow} \simeq 0.11$
- **Lego Tank**:
  - $V \simeq 1$ cm/s; $R_{tank} \simeq 17.5$ cm
  - At 2.5 rpm, $T_\Omega / T_{flow} \simeq 0.12$



Match Their Ratios

- **Atmospheric flow** (at $z \simeq 10$ km):
  - $V \simeq 100$ m/s; $R_P \simeq 6370$ km
  - $T_\Omega / T_{flow} \simeq \underline{0.11}$
- **Lego Tank**:
  - $V \simeq 1$ cm/s; $R_{tank} \simeq 17.5$ cm
  - At 2.5 rpm, $T_\Omega / T_{flow} \simeq \underline{0.12}$

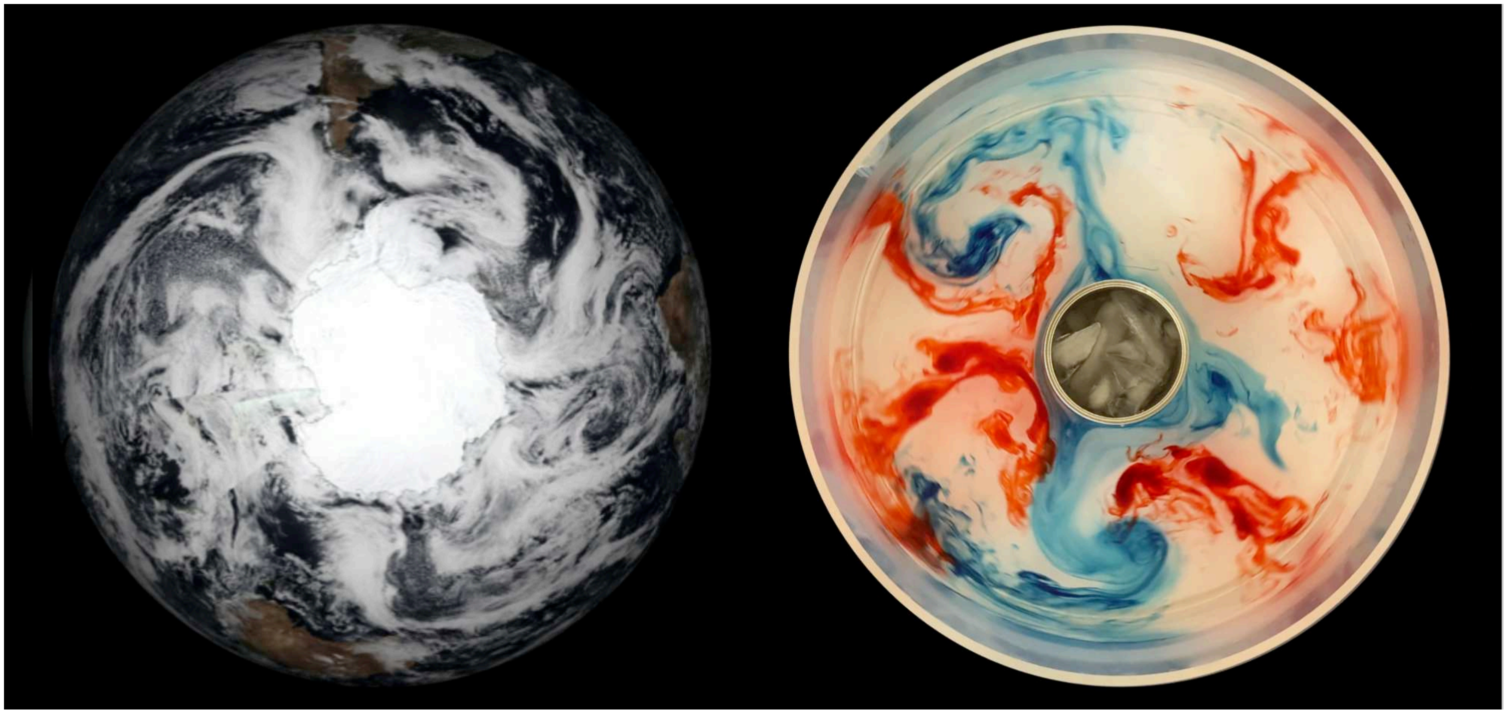


Take Aways

- ***Similar dynamics when time scale ratios are comparable***
  - Planetary scale flows: $T_\Omega / T_{flow} < 1 \longrightarrow$ rotation dominates!
- $V/(2\Omega L)$ is ***NOT* sensitive** to fluid's **density, viscosity,…**
- Can use **water** to **model oceanic *OR* atmospheric** dynamics
  - **Scale Modeling**: select (V, Ω, L) such that $V/(2\Omega L)$ is in the right ballpark

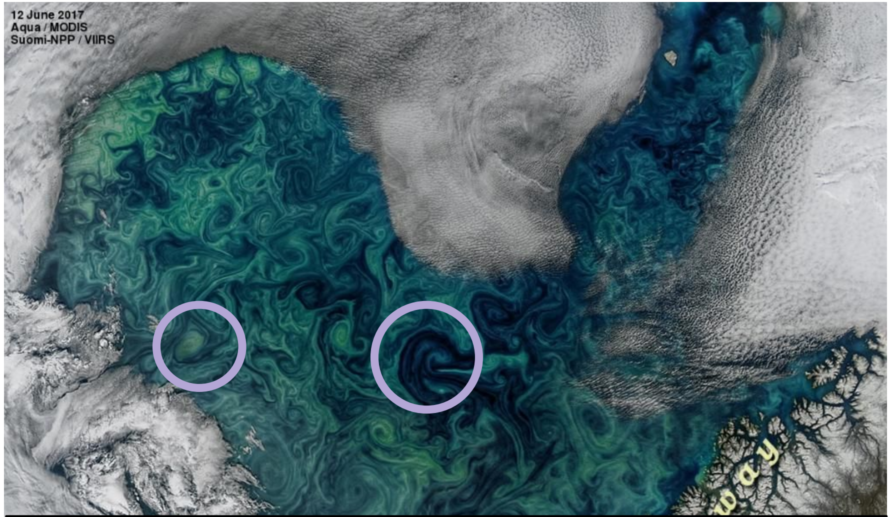
Scale Modeling

Questions? *aka "How can that little tank act like a planet?"*



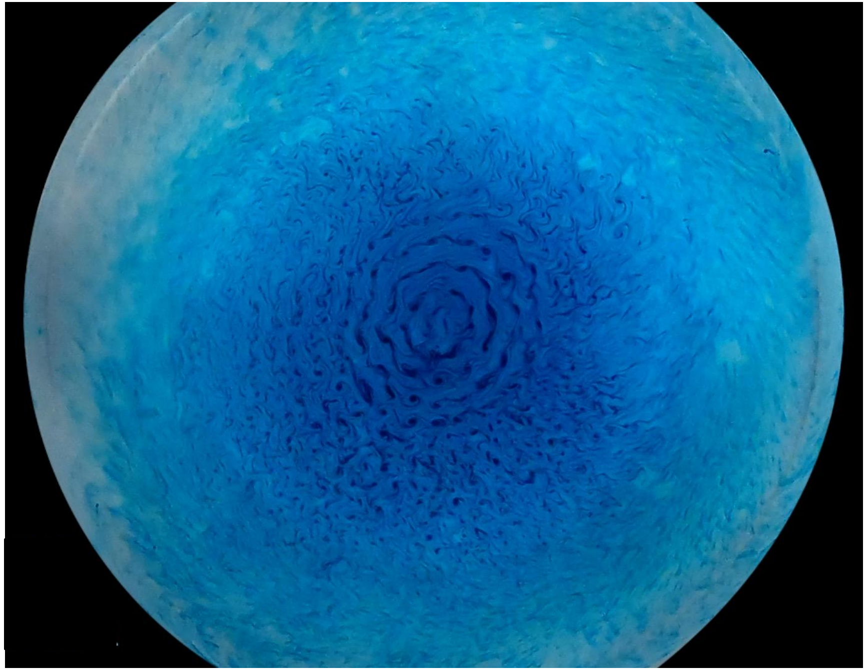
Jon Aurnou (aurnou@g.ucla.edu)

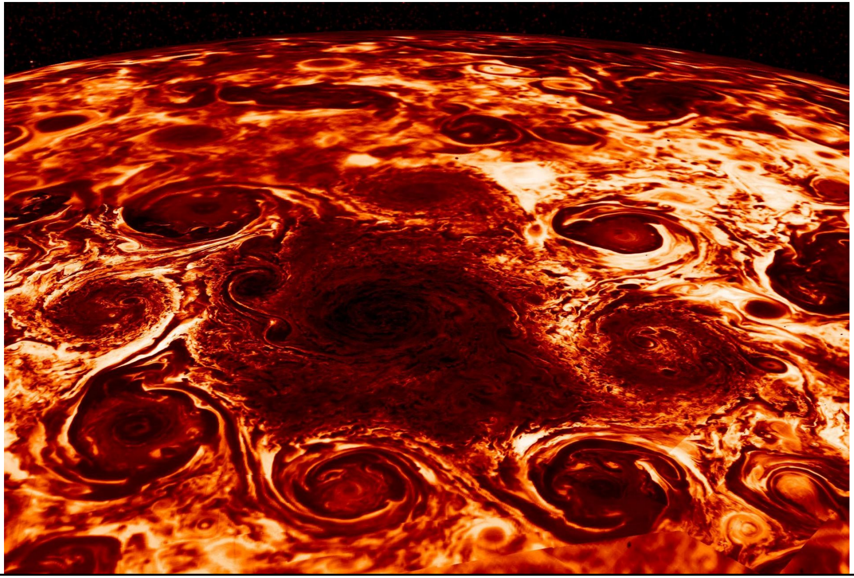
We see structures like we saw in the rotating tank in Earth's Ocean



Swirling eddies/vortices showing phytoplankton productivity in the Norwegian Sea

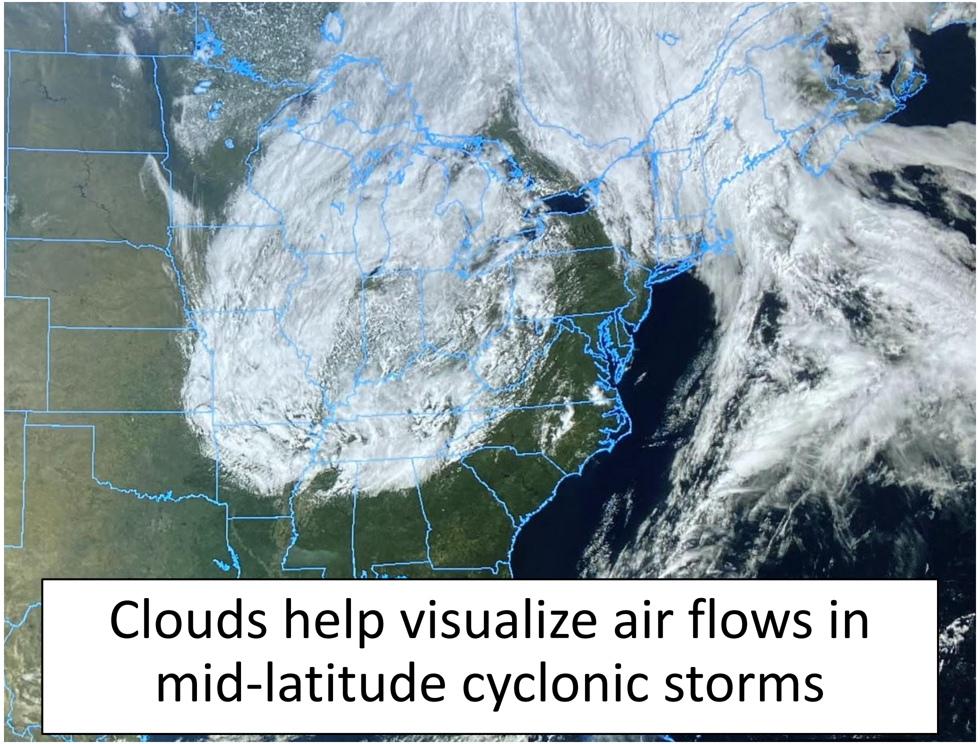
We see structures like we saw in the rotating tank on Jupiter





"Vortex crystal" at North Pole of Jupiter; it rotates faster than Earth!

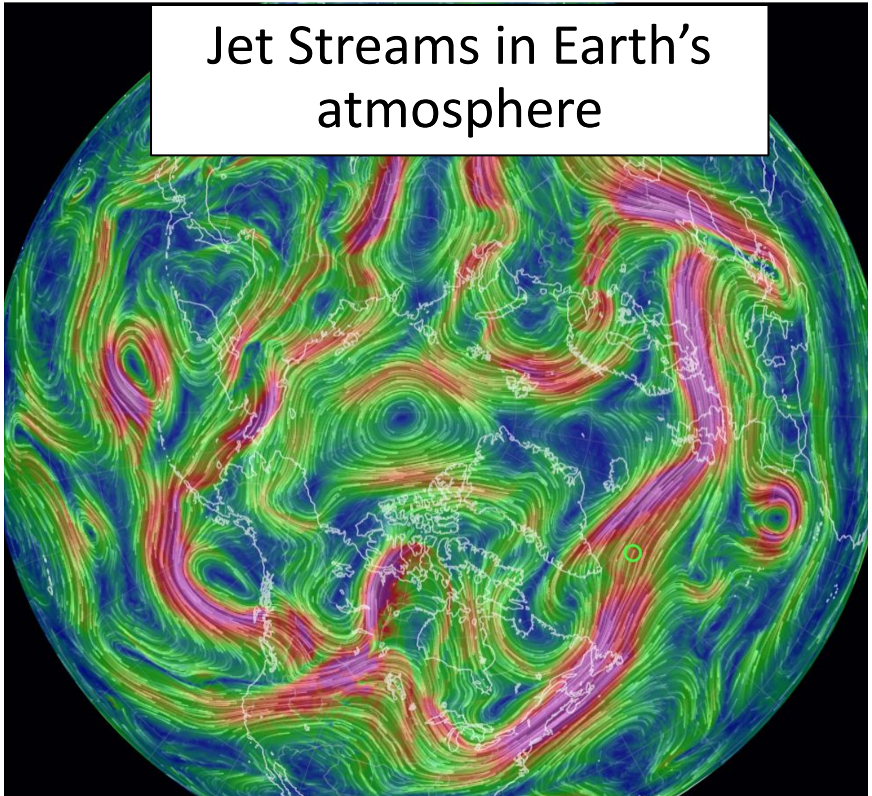
We see structures like we saw in the rotating tank in Earth's Atmosphere

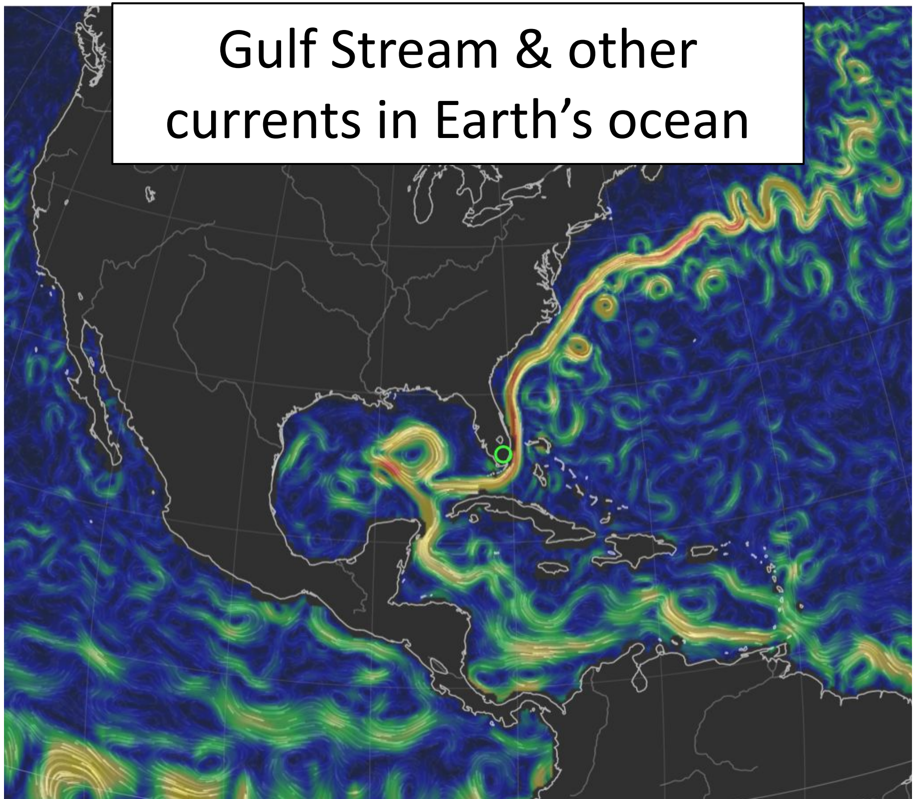


Clouds help visualize air flows in mid-latitude cyclonic storms

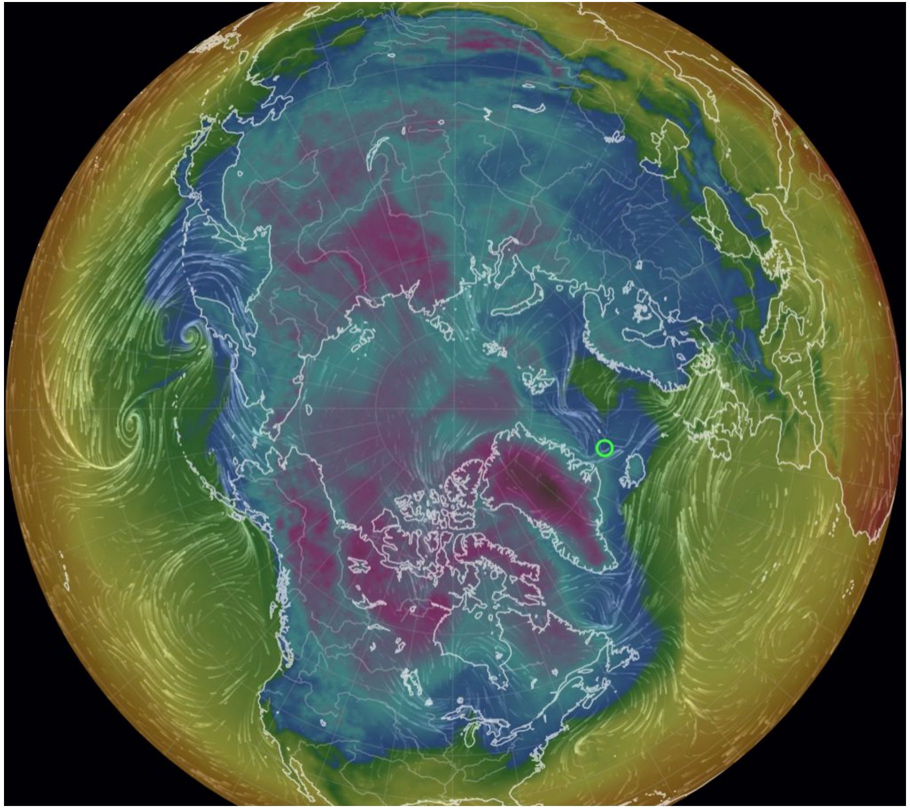
DIYNAMICS

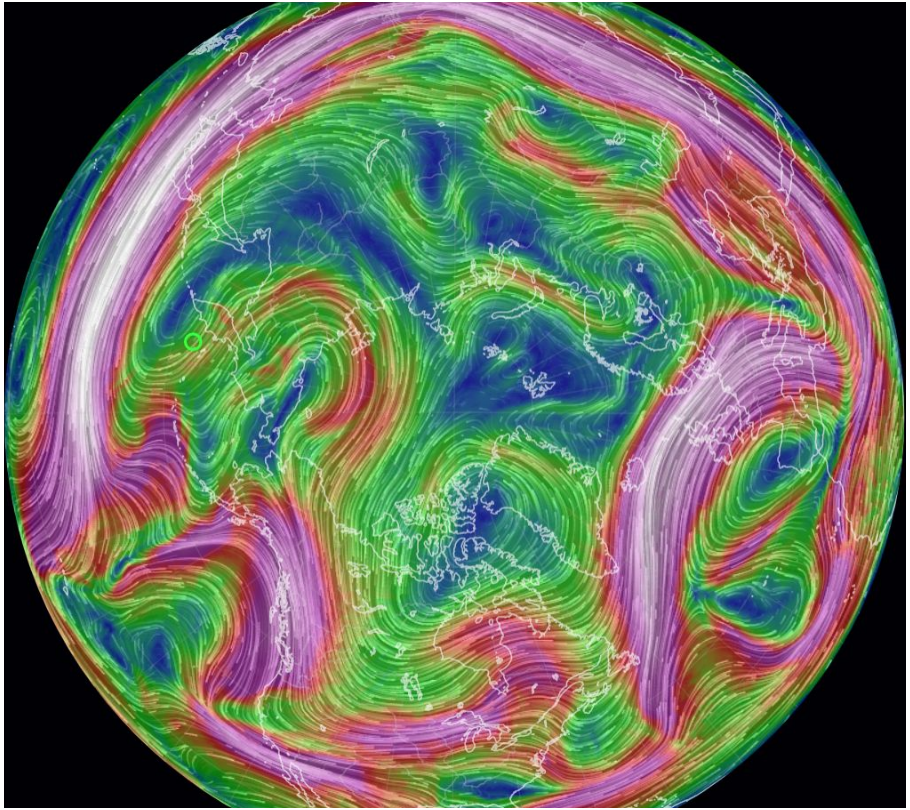
Interactive Tools on Earth.Nullschool.net can help us visualize fluid flows on Earth



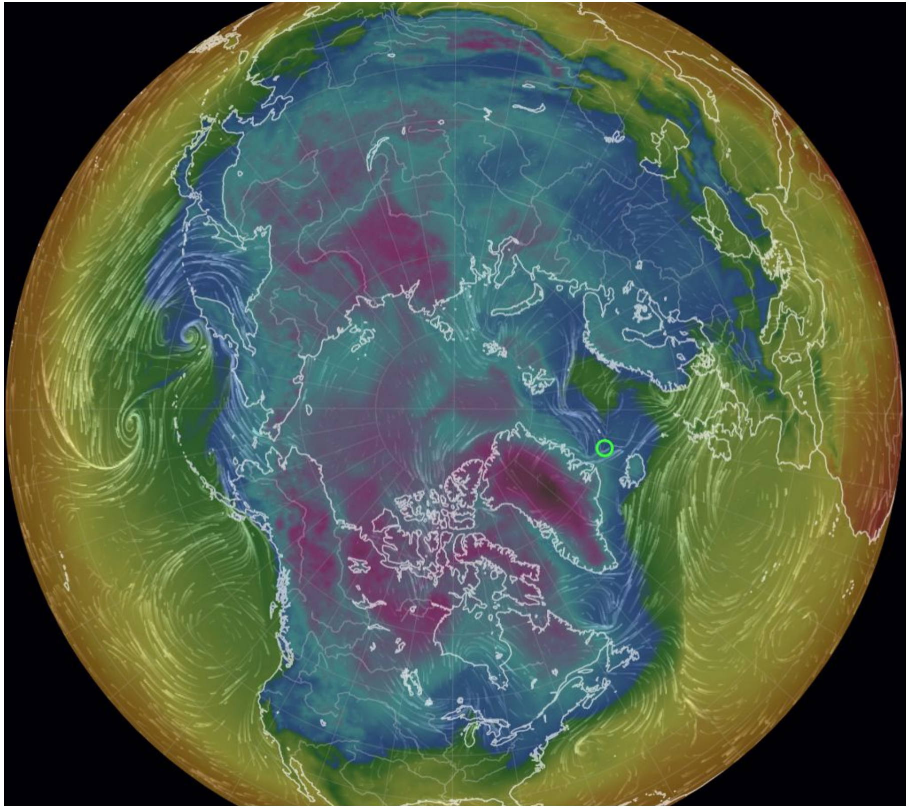


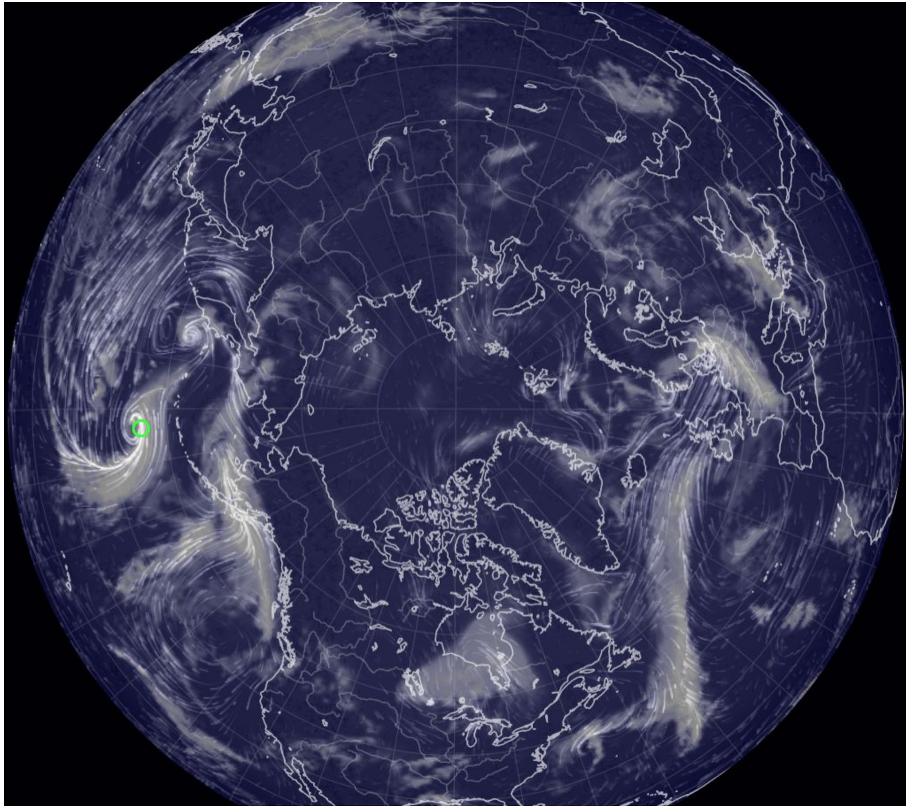
Earth.Nullschool.net Example: Near surface temperature contrasts and 10 km jet stream



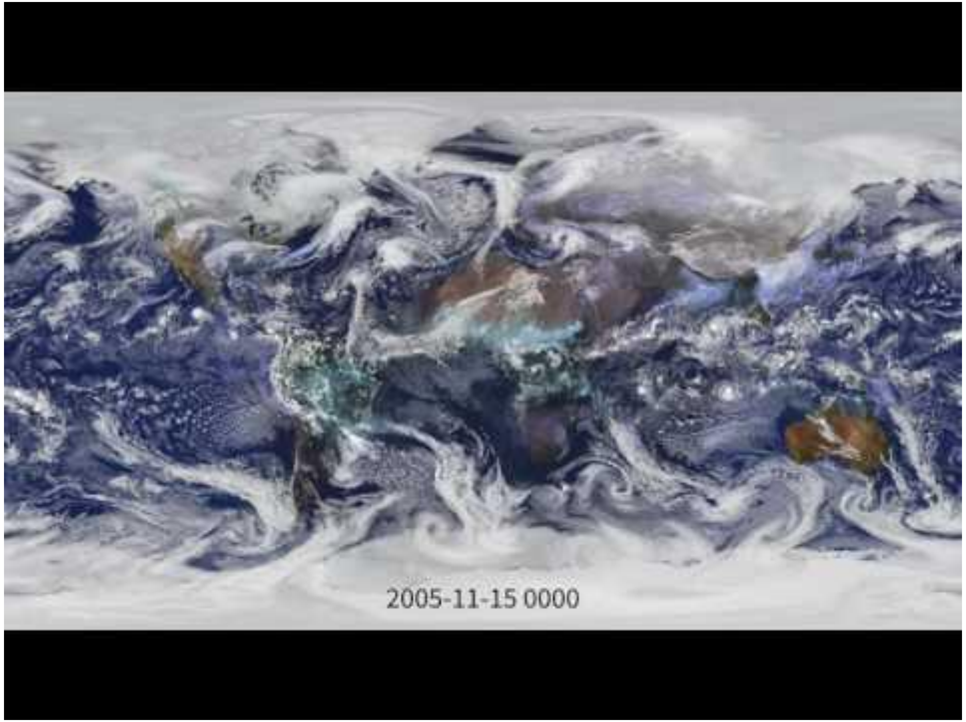


Earth.Nullschool.net Example: Near surface wind convergence, rising motions, and clouds





Climate Modeling: Importance of fluid flows, jets, and horizontally rotating systems



Why? How? - Rotating Tanks can help us understand the fundamental physics

DIYnamics experiments can replicate:

- Earth’s ocean (phytoplankton bloom structures)
- Vortex crystal on Jupiter
- Earth’s atmosphere (mid-latitude storms, jet stream)
- Earth’s climate system

Hands-on experiments can help demonstrate and teach the fundamental physics in these systems

Demo Carnival!?

Break into six teams, one per demonstration

Listed on next slide

Tomorrow, each team will perform a mini-teaching lesson w/ their selected demo

"See / do / teach" model

Now: pick yours, watch us perform that demo ("see"), and sketch out w/ your group the associated teaching activity

Tomorrow: 1-hour session to practice ("do")

Then the actual carnival ("teach")

Demos to choose from for the carnival

1. 2D rotating flow and “phantom” obstacles (Taylor columns): Indrani
2. Hadley cells (thermal wind): Spencer (must be w/ the vase)
3. Mid-latitude storms (baroclinic instability): Juan
4. Flow near boundaries (Ekman layers): Alex
5. Pacific garbage patch (gyre circulations): Jordyn
6. Storms on Saturn and Jupiter (rotating convection): Jon

~20 min discussion: How to integrate this into your local teaching environment

5 min with those around you (groups of ~4), then 15 min with everyone

What are the biggest outstanding potential roadblocks/questions/concerns you have about taking this into your classroom / outreach?

Before we adjourn for the day

Now: “road check” mandatory feedback exercise

This afternoon:
Teaching Atmospheric Dynamics mini-workshop, 1:30-4pm
Encourage all to attend! Room: Appleby 3

Tomorrow:
See you all at 8:30am, same room!

END THURSDAY
BEGIN FRIDAY

Guidelines for the demo carnival

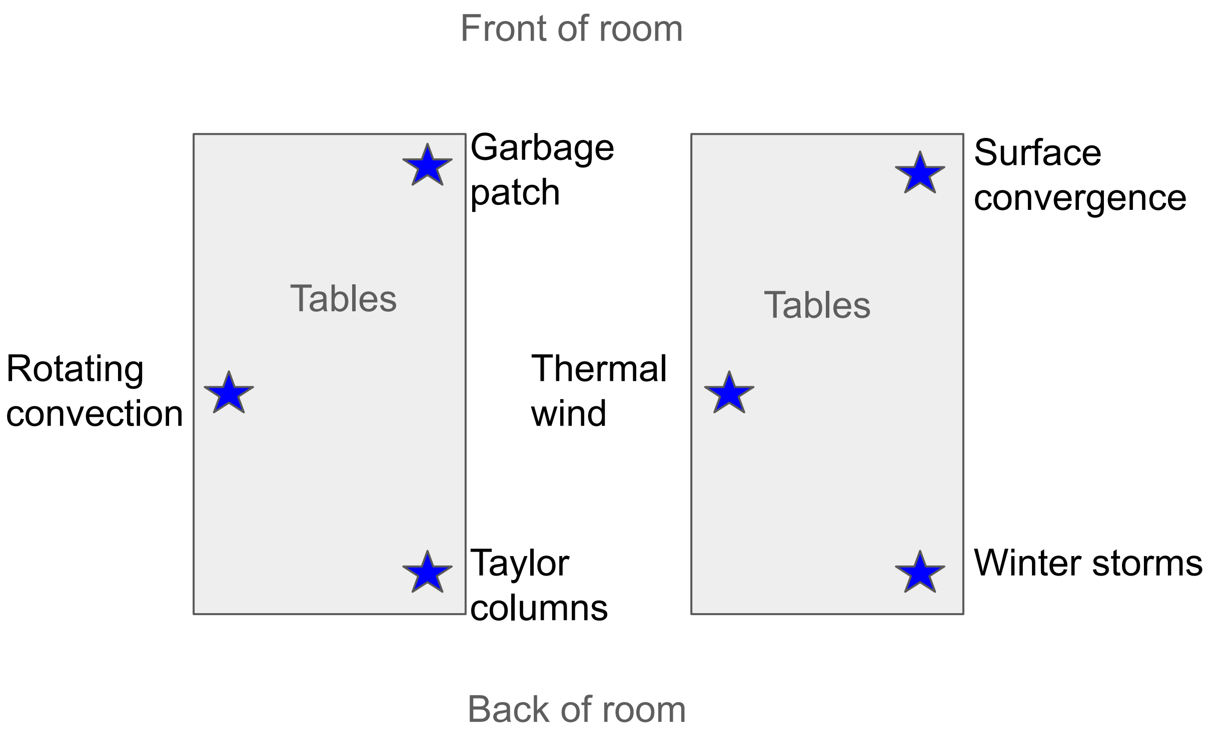
~8 minutes per demo
But you'll get to spin it up in advance

Goal isn't just performing the demo
but using it to teach the underlying concepts!

Ways to engage:

- Ask students what they predict/see/learn before/during/after
- Avoid passive science magic show!
- If possible, have student(s) physically participate in some capacity

Map of demo carnival locations



Demo Carnival!

Order of presentations:

1. Mid-latitude storms
2. Thermal wind ***begin spinning up during #1
3. Taylor columns ***begin spinning up during #2
4. Surface convergence ***etc.
5. Pacific garbage patch
6. Rotating convection

Tips and troubleshooting

Tape the baseplate to the table

No tape? Put something heavy (textbook) behind the motor

Only move the tank and rotating platform when the tank is empty

And lift by the base, NOT the sidewall

Use cups and/or hand siphon to empty as much as possible

Then can tip and pour when just a little water left

DIYnamics

Tips and troubleshooting

Dye sinking too fast? Dilute it w/ water.
Less dense=sinks slower

Try not to bump into the tables!
But demos mostly robust to moderate bumps, which are ~inevitable

Tips and troubleshooting

Camera in rotating frame is great!
Can zoom/facetime/etc. from phone to projector

Contrasting demos is great!
Rotating v. non-rotating, ice v. no ice,
northern v. southern hemisphere!

Ending w/ “play time” is great!
C.f. surface convergence team

Tips and troubleshooting

Changing parameters on the fly can be great!
E.g. turn off rotation, turn back on

Get students physically involved to extent possible
Have them stir, drop the dye, choose the color, etc.

Useful demo of how Earth being sphere alters the local “effective” rotation: Lego figurines and inflatable globe

Closing discussion

10 minutes w/ those around you, then 10 the whole group

Potential topics:

- Outstanding challenges, questions, and concerns?
- Getting support and staying connected after the workshop
- What resources would be most useful to you moving forward?

Parting thoughts while you complete the evaluations

Later this year (~2-3 months from now): retrospective judgment survey.
Please complete it!

The kits are yours to take home!
We have boxes and tape that you can take as checked luggage

Stay in touch! DIYnamicsTeam@gmail.com, @DIYnamicsTeam on Twitter
We are eager to help you incorporate this into your teaching!

More resources: https://www.diynamics.github.io, DIYnamics YouTube channel, this workshop mailing list. We will share workshop slides, PDFs, and more!

Resources

DIYnamics

Resources

- DIYnamics Webpage
  - Four current Kits: Lego, Technics, DJ, HT3
  - Blog Page
  - DIYrotate
- YouTube Pages:
  - DIYnamics, Jordyn, SpinLab
  - earth.nullschool.net; EOS Earth Observatory
- Weather in a Tank (MIT)

DIYnamics Page

- https://diynamics.github.io
  - Kits
  - Blog Page
  - DIYrotate

YouTube Resources

- YouTube DIYnamics Team
- Jordyn’s Page
- SpinlabUCLA

Web Resources

- earth.nullschool.net
- https://earthobservatory.nasa.gov

- http://weathertank.mit.edu

Shipping Your Kits!

- We will Box Them Up at the end of today's session
- One possibility: **USPS in Coffman Memorial Union**
  - Ground Floor G-11
  - Hours today 1-5pm