Project 2: Tracer transport

Tracer: *"Any fluid property used to track the flow velocity and circulation patterns" (Wikipedia)*

Two types of tracers:

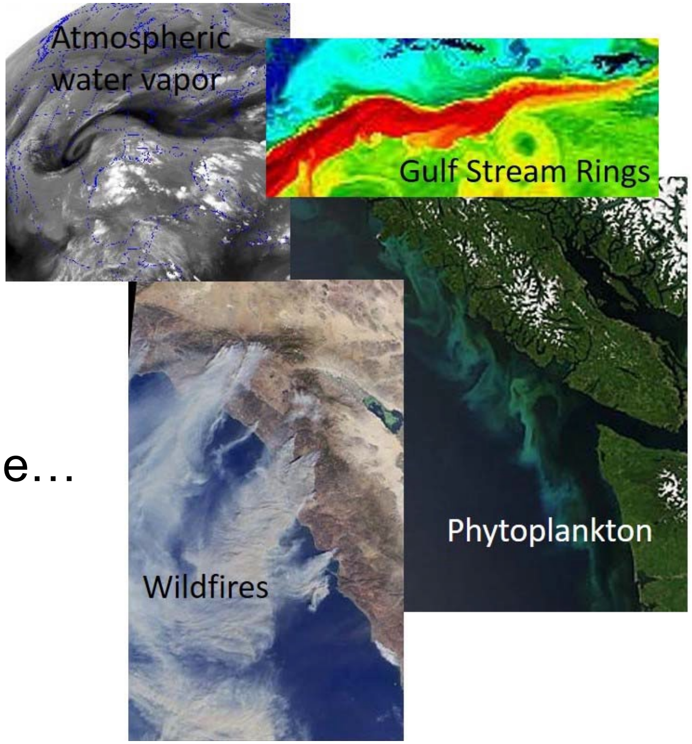
1) **Passive:** a tracer which does not effect the flow

2) **Active**: a tracer which interacts with the flow and can change it

Project 2: Tracer transport

In the atmosphere:

- Aerosols
- Water vapor
- Temperature
- Dust, volcanic eruptions (ash)
- Checmical tracers: carbon (wildfires), ozone…
- Radioactive plumes (e.g., Fukushima)



In the ocean:

- Biological substances (e.g., Phytoplankton)
- Marine pollution- plastics in the ocean
- Oil Spill
- …

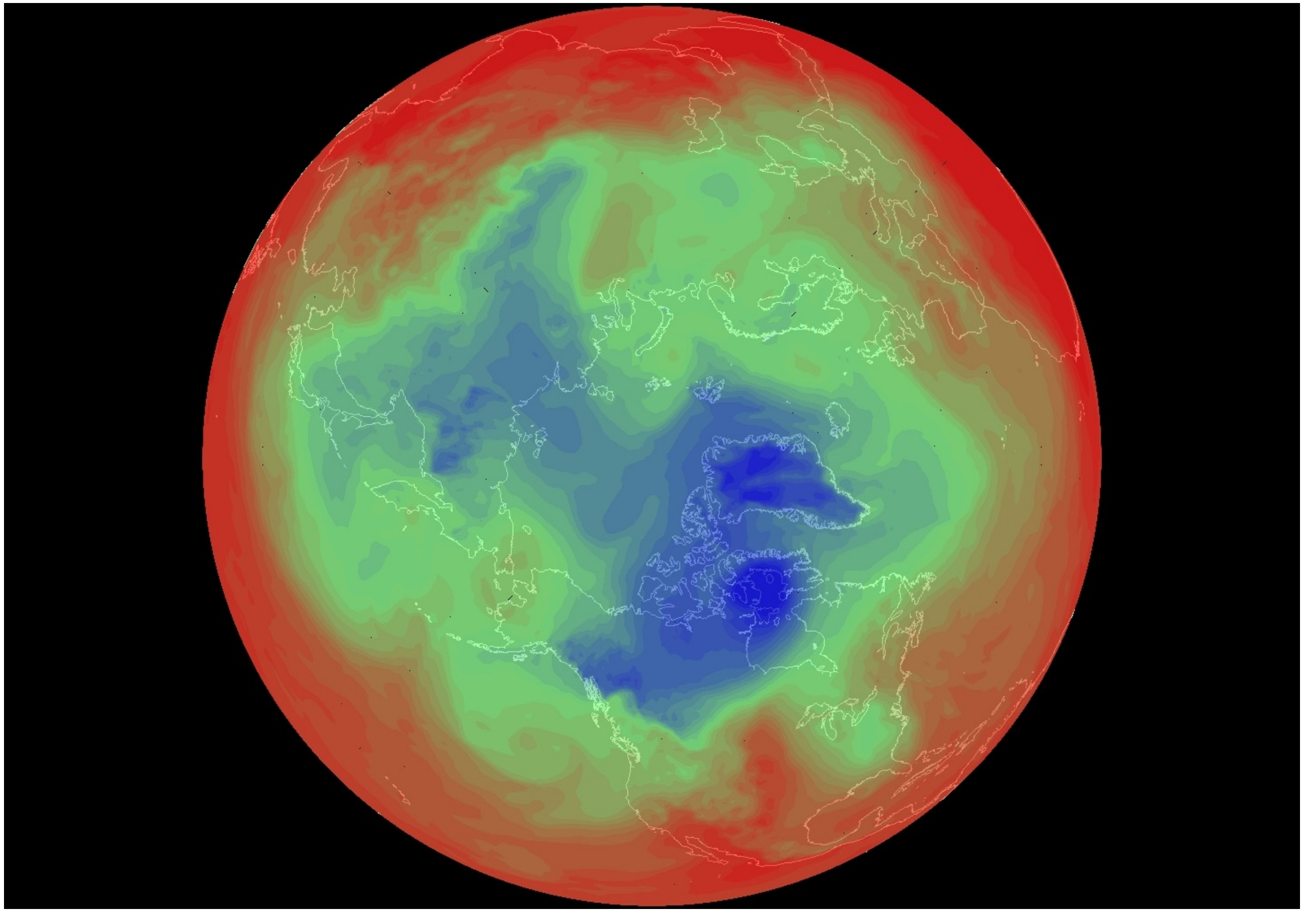
In Project 2 we will explore how tracers are transported by winds and currents in the atmosphere & Ocean and how their dispersal depends on the motion and Earth's rotation

P2: tracers transport

Winds carry their properties as they move around the globe

Temperature
at 850 mb, ~1.5 km

Color scale:
red =hot
blue=cold

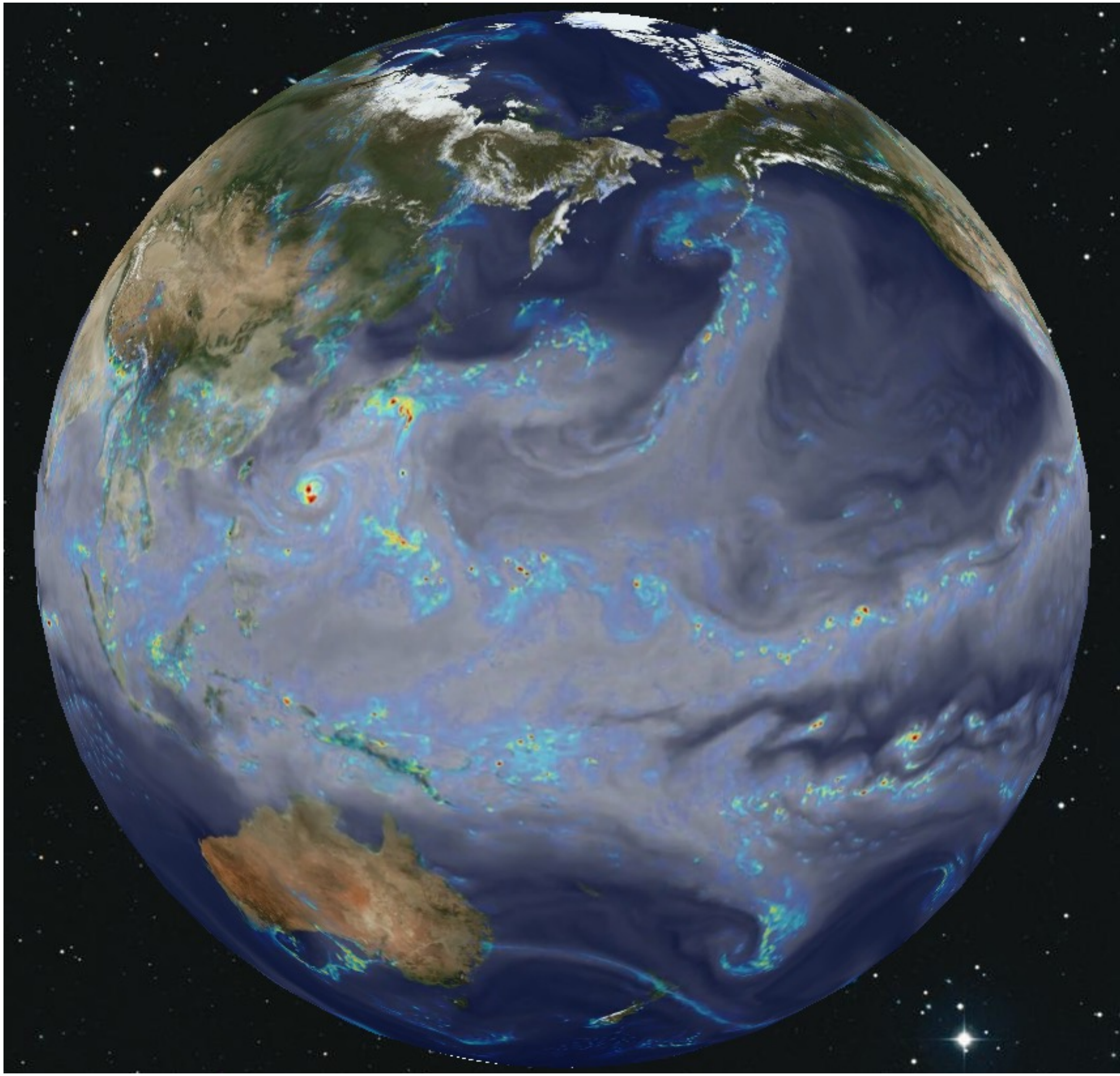


GFS analyses loop - winter 2009

Water vapor

Total precipitable water (white)
and
rainfall (colors 0-15 mm/hr;
red=highest).

NASA Goddard Earth Observing System Model (GEOS-5) – 10 km global simulation



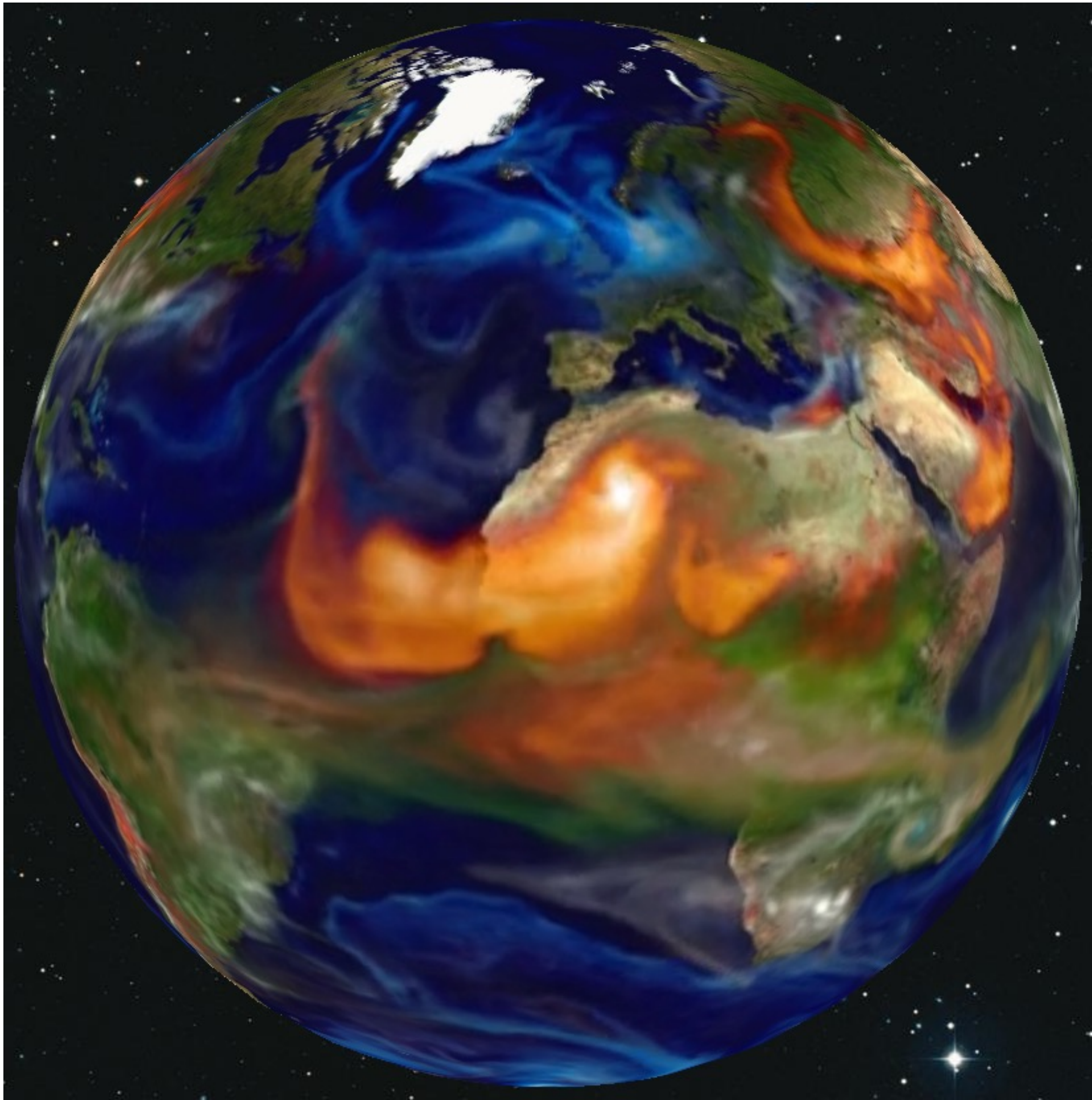
Movie is available on the EsGlobe under "GEOS-5 Water Vapor"

Aerosols

The colors show four different aerosols:

- grey=sulfate
- green=organic and black carbon
- blue=sea-salt
- red=dust

The simulation uses GEOS-5 and the Goddard Chemistry Aerosol Radiation and Transport (GOCART) Model.



Movie is available on the EsGlobe under "Atmospheric aerosols"

Fukushima radioactive aerosols

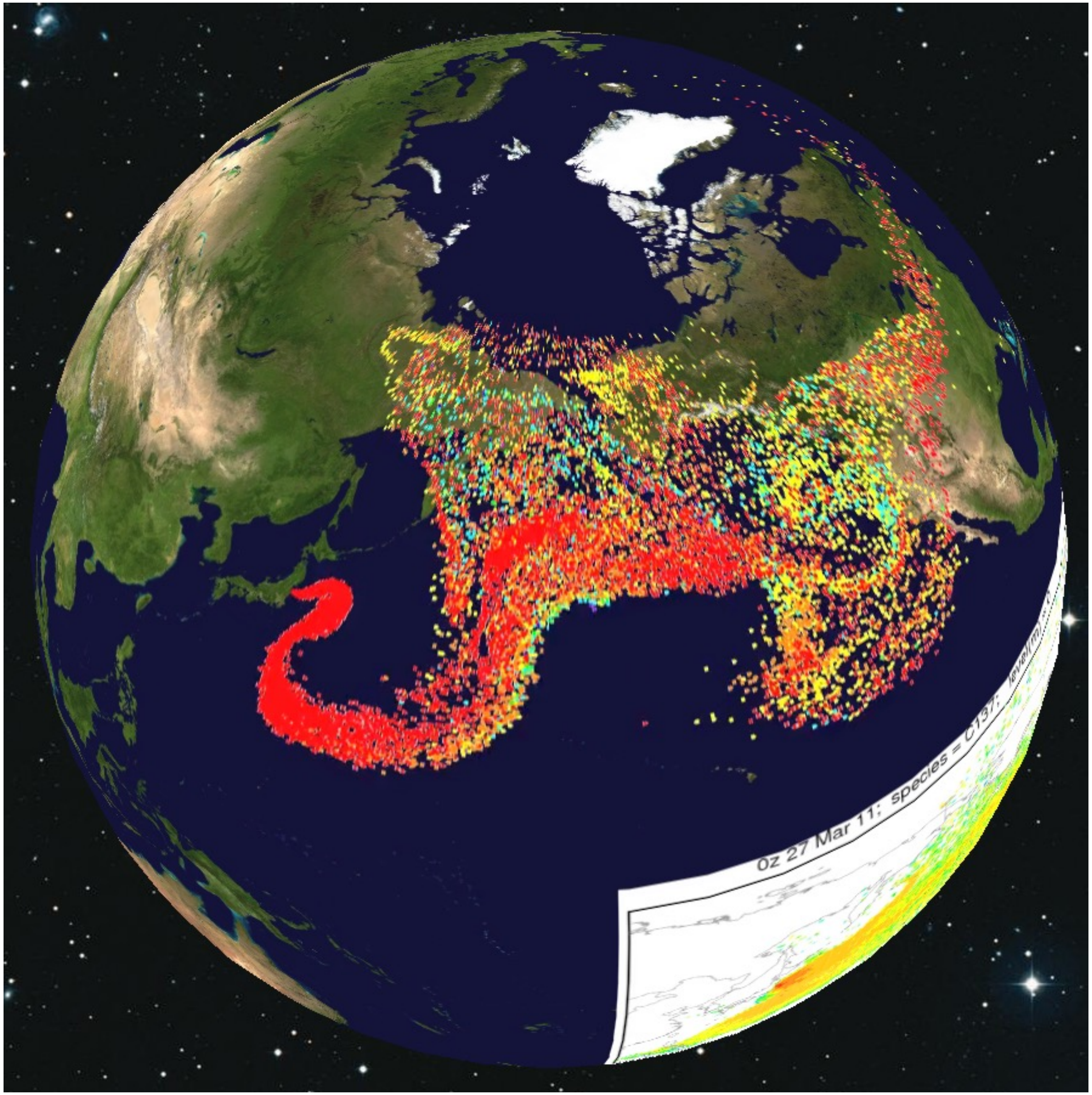
March 11, 2011

Cesium-137 emitted from Fukushima

Each change in particle color represents a decrease in radioactivity by a factor of 10.

Radioactivity decreases due to removal by rainfall and gravitational settling.

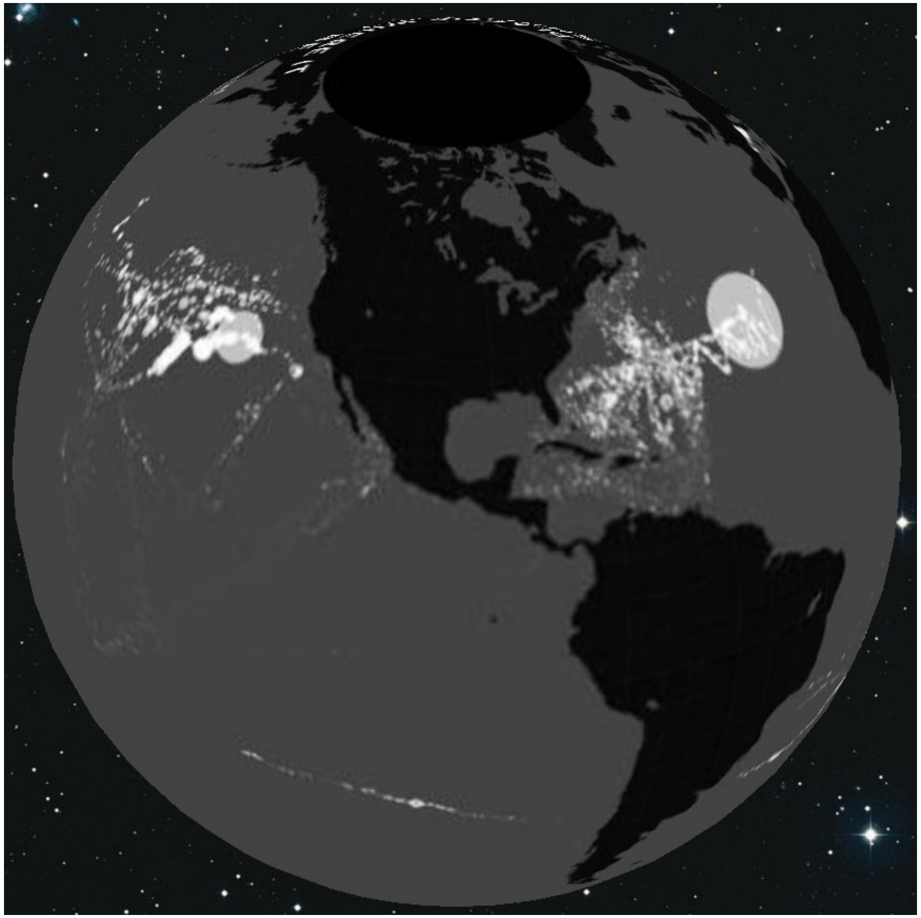
Decay is not a factor for Cesium in this short duration simulation compared to its 30 year long-half life.



[Movie is available on the EsGlobe under "Fukushima radiation release"]

Ocean plastics

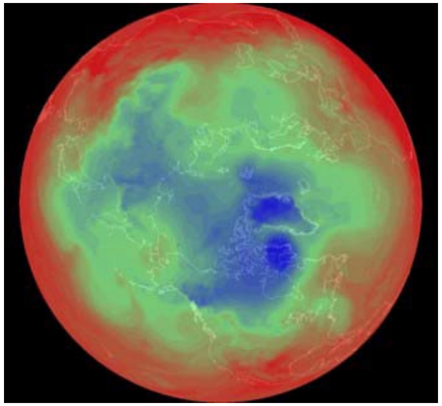
Marine pollution collected
With ~10,000 surface nets
between 1986-2013.



Ocean garbage patches
“Plastic where it shouldn’t be”

[Movie is available on the EsGlobe under “Plastic Obs from Skye Moret (SEA)”]

Project 2: Tracer transport

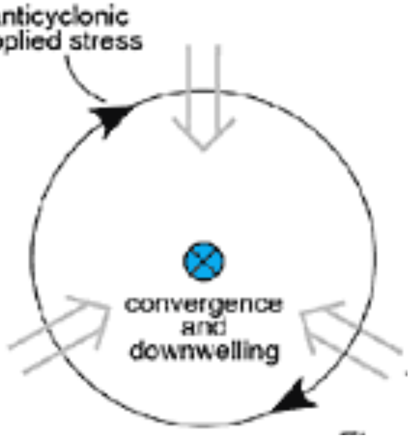


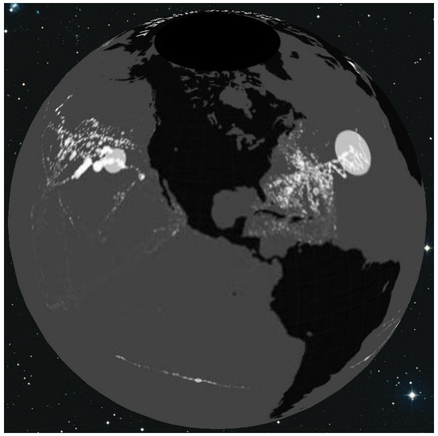
Observational analysis:

- Temperature advection in the atmosphere, transport of dust
- Plastics in the ocean (EsGlobe)

Fluid laboratory:

- Laboratory analogue of ocean ‘garbage patches’



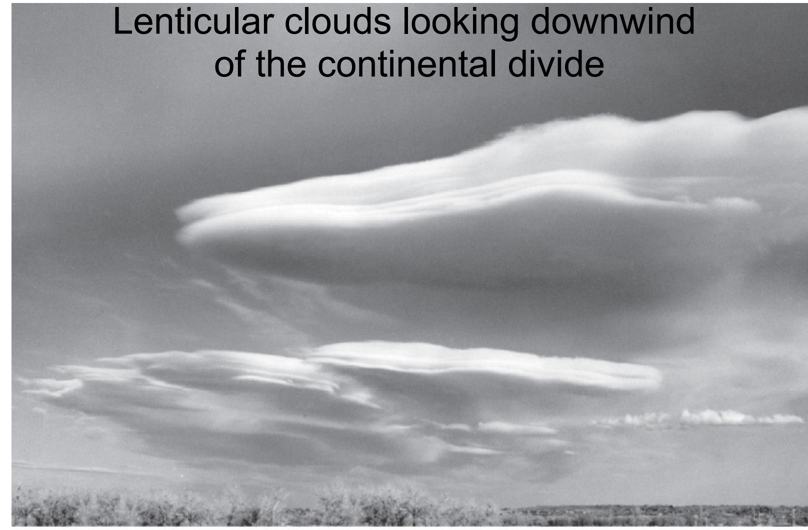


Eulerian derivative

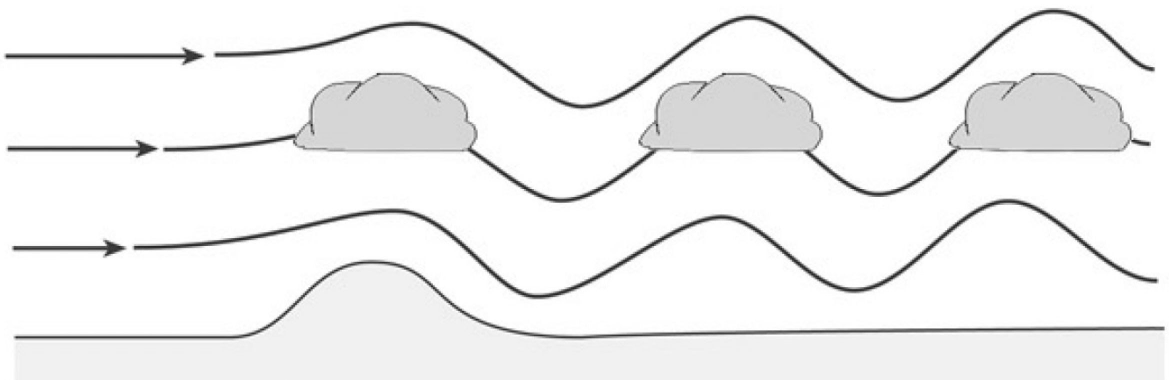
- Mountains produce Lee waves
- Steady state: pattern of clouds
- Cloud amount=C does not change with time

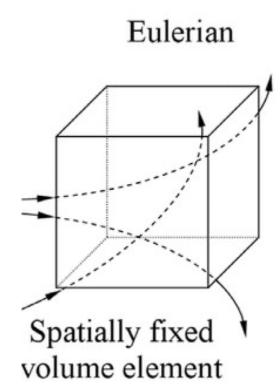
$$C = C(x, y, z, t)$$

$$\left(\frac{\partial C}{\partial t}\right)_{\substack{\text{fixed point} \\ \text{in space}}} = 0$$



(Photo courtesy of Dale Durran, University of Washington.)



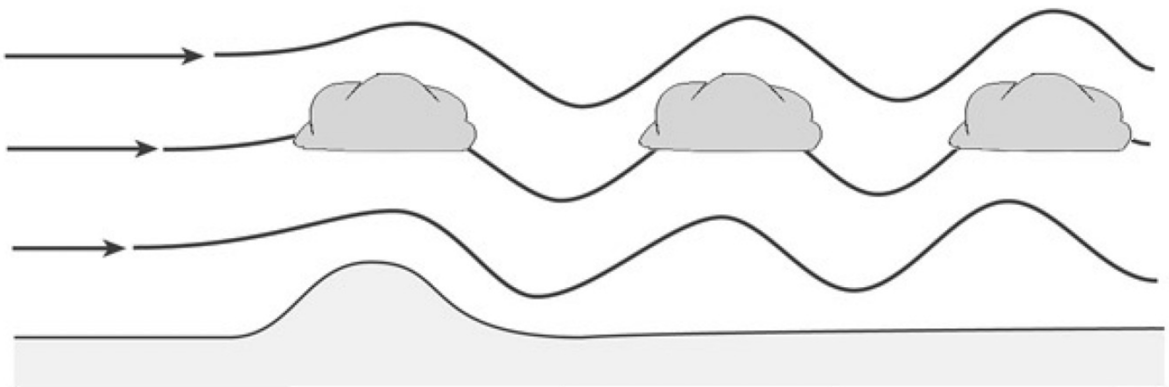


At any fixed location, cloud fraction does not change, even though the air is flowing through!

Lagrangian derivative

- However, C is not constant following a particular parcel $C = C(x, y, z, t)$
- As the parcel moves upward, it cools, water condenses out, cloud forms → C increases
- As the parcel moves downward, the water goes back into the gaseous phase, the cloud disappears → C decreases.

$$\left(\frac{\partial C}{\partial t}\right)_{\substack{\text{fixed}\\\text{particle}}} \neq 0$$



Lagrangian derivative

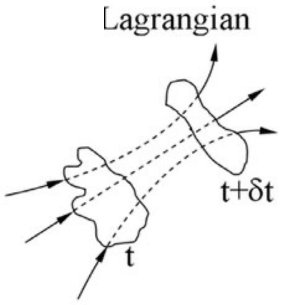
- For small deviations of $C = C(x, y, z, t)$, which is a function of position and time:

$$\delta C = \frac{\partial C}{\partial t}\delta t + \frac{\partial C}{\partial x}\delta x + \frac{\partial C}{\partial y}\delta y + \frac{\partial C}{\partial z}\delta z$$

$$(\delta C)_{\substack{\text{fixed}\\\text{particle}}} = \left(\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z}\right)\delta t$$

Where we used: $\delta x = u\delta t,\ \delta y = v\delta t,\ \delta z = w\delta t.$

The variation of a property C following an element of fluid!



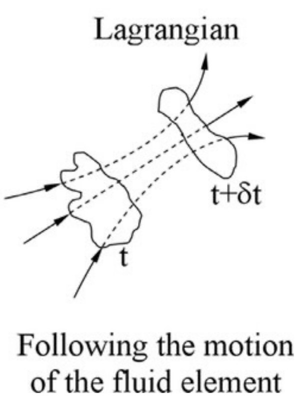
Following the motion of the fluid element

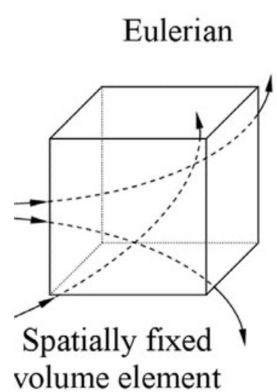
Lagrangian derivative

$$\left(\frac{\partial C}{\partial t}\right)_{\substack{\text{fixed}\\\text{particle}}} = \underbrace{\frac{\partial C}{\partial t}}_{\text{fixed point}} + \underbrace{u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z}}_{\text{advection}} = \frac{DC}{Dt}$$

Where $\frac{D}{Dt} \equiv \frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z} \equiv \frac{\partial}{\partial t} + \mathbf{u}.\nabla$

$$\nabla \equiv \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right)$$





$$\boxed{\frac{D}{Dt} = \frac{\partial}{\partial t} + \mathbf{u}.\nabla}$$

Lagrangian Eulerian Advection

Examples:

1) Velocity and position of a fluid parcel-

$$u = \frac{D}{Dt}x; \quad v = \frac{D}{Dt}y$$

$$x = \int udt; \; y = \int vdt$$

Where u is the speed in the x direction and v is the speed in the y direction

2) Tracer Transport- assume T is some conserved tracer

$$\frac{D}{Dt}T = 0$$

Fluid parcels conserve (except for small diffusive processes) the concentration of dye

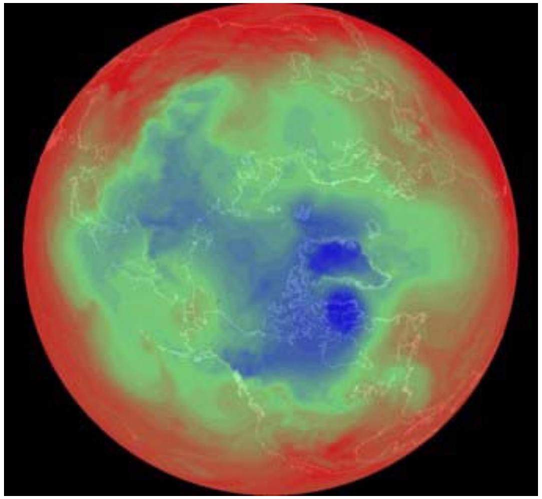
Examples:

3) Temperature advection-

$$\frac{D}{Dt}T = 0$$

Assuming temperature is conserved (which is not entirely correct), and that meridional (north-south) advection is dominant, we can write-

$$\frac{\partial T}{\partial t} \simeq -v\frac{\partial T}{\partial y}$$



red =hot
blue=cold

Where $\frac{\partial T}{\partial y} < 0$

Hence, $v < 0 \Rightarrow \frac{\partial T}{\partial t} \simeq -v\frac{\partial T}{\partial y} < 0$

$v > 0 \Rightarrow \frac{\partial T}{\partial t} \simeq -v\frac{\partial T}{\partial y} > 0$

In regions where the cold air is moving south ($v<0$) the local rate of change of temperature is negative (cooling). Similarly, local warming when $v>0$

Data lab- 2 next classes

Transport in the atmosphere-

- Advection of dust
- Temperature advection and fronts
- Climate change impact on temperature advction