3 Exploring fluid transport using Atmospheric and Oceanic data

We will use EsGlobe to view atmospheric and oceanic flow trajectories and how tracers, such as aerosols, water vapor and particles (e.g. plastics floating in the surface ocean), are dispersed around the globe by winds and currents. In this way we will explore how parcels of fluid carry properties around with them as they move.

Please use your own vms: http://cmpo5.mit.edu:90xx to access EsGlobe.

3.1 Transport of particles in the global ocean and the dynamics of 'garbage patches'.

We use EsGlobe to explore the patterns and timescales of ocean circulation and how ocean currents transport properties around the globe. Trajectories are computed from flow fields obtained by blending global observations of the ocean with an ocean model. We will contrast the trajectories of particles released in the surface ocean to those released in the near-surface interior ocean. The former enable us to detect regions of surface divergence and convergence. We will see that the subtropical gyres of the oceans are regions of surface convergence and so might be expected to be places where particles accumulate. This is highly relevant to the formation of the great garbage patches of the world ocean. Clear contact points can be made with the wind-driven ocean circulation experiment that we carried out in the laboratory in Section 2.

EsGlobe supports an 'ocean tracker' which enables one to launch virtual particles in to an evolving ocean circulation and track them around. The tracker allows one to launch particles at a depth of 5m (equivalent to the surface), 55m and 105m — see Fig.9 for an example. Particles launched at the surface will be under the direct influence of the wind blowing over it and so will be carried by both geostrophic and ageostrophic currents. Lower down in the water column — e.g. at 105m — the direct driving of the wind will not be felt and one might expect the flow to be geostrophic.

Our activity comprises two parts:

1. Exploration of space scales and timescales of ocean circulation in the interior, subsurface ocean.

2. Exploration of trajectories at the surface of the ocean. This is of relevance to the fate of floating plastics in the surface ocean.

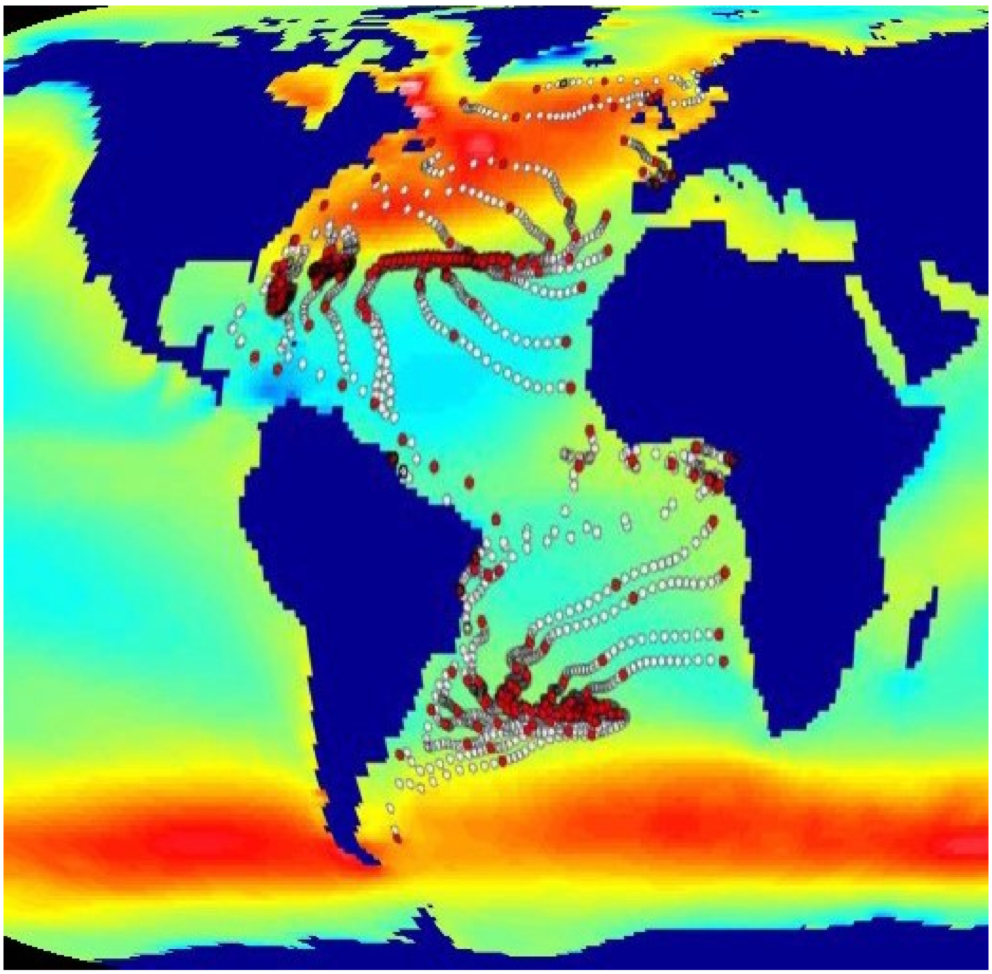

Figure 9: Trajectory of particles launched in to the surface of the Atlantic ocean from places around the coasts. White dots are plotted every month along the trajectory, red particles every year. The background color indicates the pattern of prevailing windstress: red eastward, blue westward.

To interpret your trajectories in the context of the general circulation of the ocean, if you have time you can inspect key observed properties of ocean circulation — currents, winds, temperature, salinity etc — also using the EsGlobe.

3.1.1 Space scales and timescales of interior ocean circulation

Launch particles (both single and multiple) in to the interior ocean (depth of 105m) to explore typical space and timescales.

Focus on the:

- North Atlantic
- North Pacific
- Southern Ocean and Circumpolar flow around Antarctica.

White dots represent the position of particles after 1 month, red dots after one year.

Can you identify closed circulation patterns? These are known as ocean gyres — you can find them in subtropical and subpolar regions in all the major basins, both in the northern hemisphere and the southern hemisphere.

What are typical space and time scales?

Use them to estimate $R_{timescales}$ — Eq.(1) of Project 1 notes — and hence the Rossby number appropriate to an ocean gyre. Is it large or small?

Is the interior flow in geostrophic balance?

3.1.2 Trajectories of particles in the surface ocean

Launch particles (both single and multiple) in to the surface ocean (depth of 5m) to explore typical space and timescales.

In which ways are the trajectories similar and/or different from the subsurface ones?

Launch particles in to regions where the wind stress is predominantly from west to east, colored red in Fig.9? What do you observe?

And east to west: colored blue in Fig.9?

Can you make contact points with your laboratory experiment in which the stress was created by fans?

Contrast the behavior of particles released in to wind belts in the SH vs the NH. Do you notice any difference?

Creating 'garbage patches' Launch particles in to the ocean basins from their margins representing the entry of particles in to the ocean from the continents.

- Track them and determine regions where the particles preferentially congregate.
- Why do the particles congregate in these particular places? What is special about them?

3.1.3 Laboratory, real-life connections

Fig.7 shows the trajectories of paper dots from our wind-driven ocean gyre experiment at early (top) and later (bottom) times. 10-second streaks are shown.

Discuss:

- ways in which the laboratory experiment is a good/poor analogue of the behavior of your virtual trajectories driven by observed ocean currents.
- how you might improve the laboratory experiment to make it a truer analogue?

3.2 Transport in the Atmosphere

3.2.1 Calculating trajectories from wind observations

We learned in Section 1.1 how to express the rate of change of a property C of a fluid element, *following that element as it moves along*, rather than at a fixed point in space — see Eq.(1) and attendant discussion. It follows from the definition of the Lagrangian derivative, D/Dt, that the position of a parcel of fluid is related to its velocity by Eqs(3 and 4, repeated here for 2-dimensions:

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

$$x = \int u dt; y = \int v dt,$$

where u is the speed in the x direction and v is the speed in the y direction etc.

Here we will build the trajectory — (x, y) as a function of time — of a hypothetical particle of dust, moving with the wind during June of 2018 when satellite imagery revealed a persistent flow of dust from the Sahara desert moving across the Atlantic over the Southern US. In fact the last 10 days of June were the 10 dustiest for the tropical Atlantic going back 15 years — see Fig.10 — from NASA-Earth Observatory — see https://earthobservatory.nasa.gov/images/92358/here-comes-the-saharan-dust.

Using maps (handed out in class) of the height field and the wind field at the 850 mb level over the Atlantic region at: 180620 (20th June, 2018), 12 GMT; 180620 18 GMT; 180621 00 GMT and 180621 06 GMT, draw by hand the trajectories of chosen particles following the 12z wind for the first six hours, the 18z wind for the second six hours, the 00z wind for the third six hours and the 06z wind for the fourth six hours. In this way, compute a trajectory over a period of 1 day.

Compare your trajectory with one you obtain from the EsGlobe interface by launching a virtual particle in to the same flow field. The two should be rather similar. This is essentially how the EsGlobe computes trajectories: it reads in wind fields at regular intervals and performs the above integrals numerically, plotting out the positions as it goes.

Finally, estimate how long it will take for your particle of dust to reach Texas. Is your estimate consistent with what was observed by satellite, as described in the article above?

3.2.2 Rate of change of temperature at a point: temperature advection

More often than not, it becomes cold over Boston, say, because winds carry low temperatures from places where it is cold. We say that cold air is advected (carried) by the winds. We

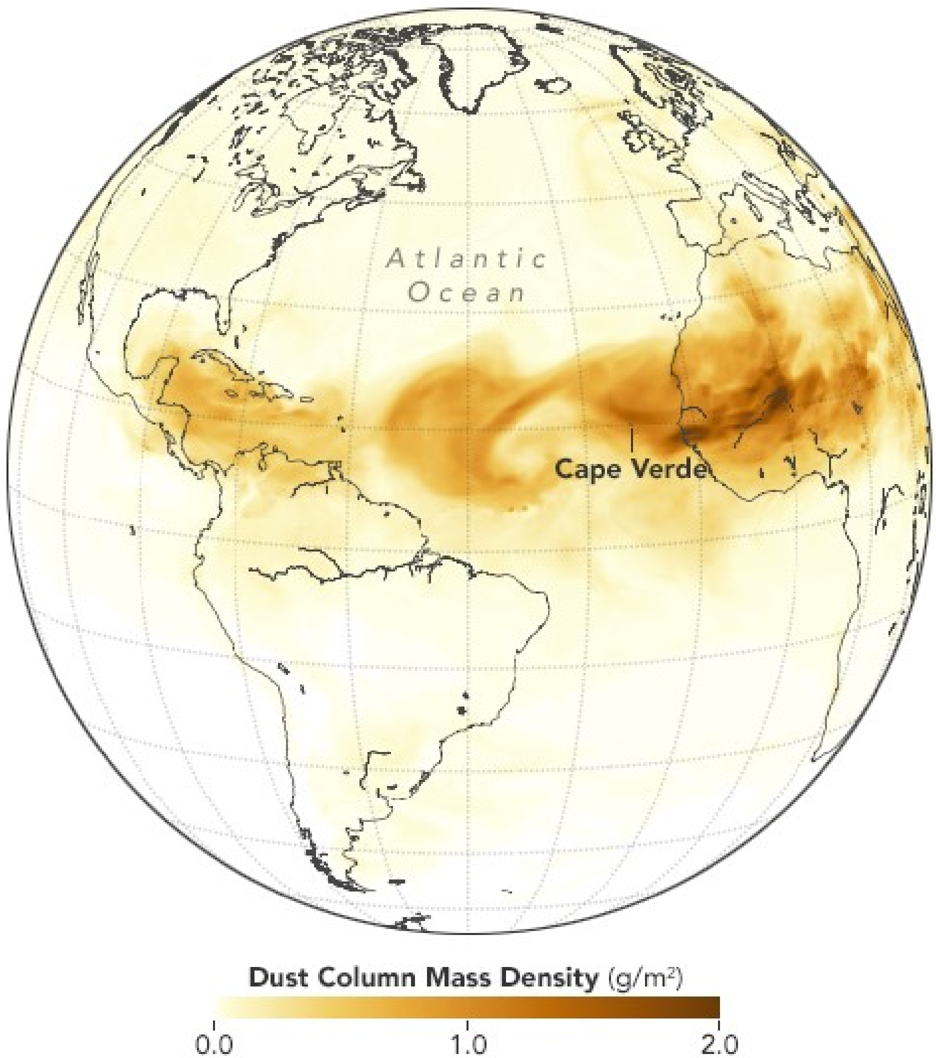

Figure 10: A cloud of dust, whipped up winds from the Sahara Desert, being carried by the trade winds over to the Caribbean, and on toward Texas. The map is from June 28, 2018: from NASA-Earth Observatory — see https://earthobservatory.nasa.gov/images/92358/here-comes-the-saharan-dust.

can write this down mathematically as:

$$\frac{D}{Dt}T = 0, \tag{11}$$

assuming that air parcels conserve temperature as they move. If the winds are predominantly horizontal (a good approximation) then:

$$(\partial T/\partial t)_{\text{at Boston}} = -u\partial T/\partial x - v\partial T/\partial y \tag{12}$$

where u is the zonal (west to east) component of the wind and v is the meridional (south to north) component of the wind, T is temperature and t is time.

If the temperature at Boston increases with time:

- then $\partial T/\partial t > 0$ and is associated with warm temperature advection (winds blowing from higher to lower temperature)

Vice versa, if the temperature at Boston decreases with time:

- then $\partial T/\partial t < 0$ and is associated with cold temperature advection (winds blowing from lower to higher temperature)

Let's test these ideas out using data by comparing the local temperature tendency at a few locations to that implied by horizontal temperature advection, as expressed in Eq.(12).

A Schematic front. Suppose a cold front has just passed over Boston. The front is oriented west to east and the temperature drops 5^oC every 100 km (as sketched in Fig.11). As the wind blows from the NW at $15kts$, where $1kts = 0.5m/s$, infer how much the temperature will be expected to drop in 12 hours due to cold air advection?

A 'Real' front. Fig.12 is an IR satellite image for January 22, 2013 at 06z, showing a band of clouds, associated with a pronounced northerly flow along the east coast of the US.

Fig.13 shows analyzed surface temperature (in ^oC) and surface wind (in kts) for the same time, January 22, 2013 at 06z. Estimate the horizontal temperature advection at Chicago-O'Hare, IL (ORD) and Pittsburgh, PA (PIT). What is the expected 6-hour temperature change due to this horizontal temperature advection?

Compare your results with the observed temperature changes revealed in the surface meteograms shown in Figs.14 and Fig.15.

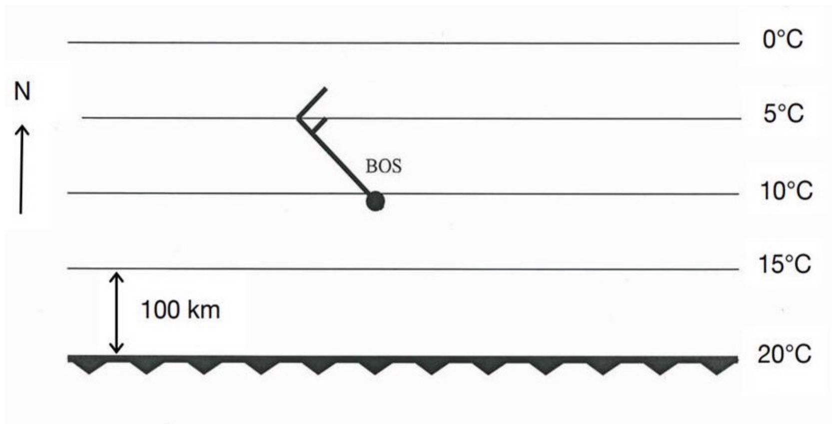

Figure 11: Sketch of a front (indicated by the thick serrated line) oriented west to east across which the temperature drops 5^oC every 100 km. The wind is blowing from the NW at $15kts$.

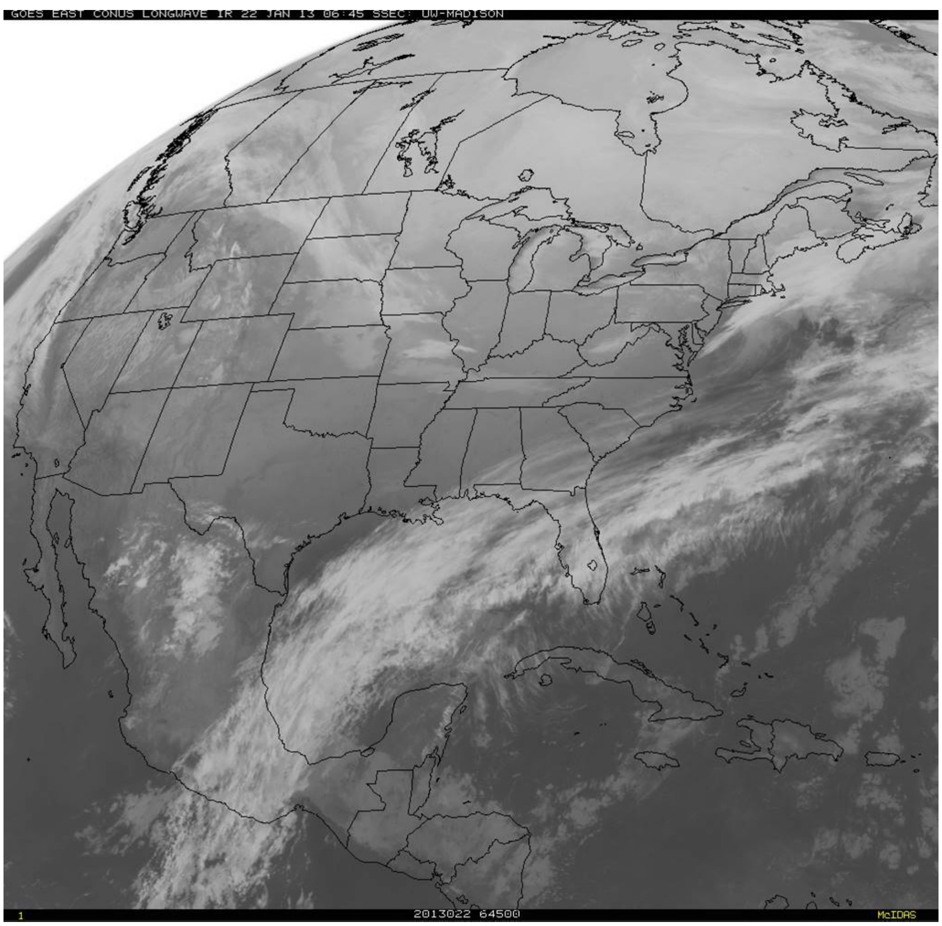

Figure 12: IR satellite image for January 22, 2013 at 06z

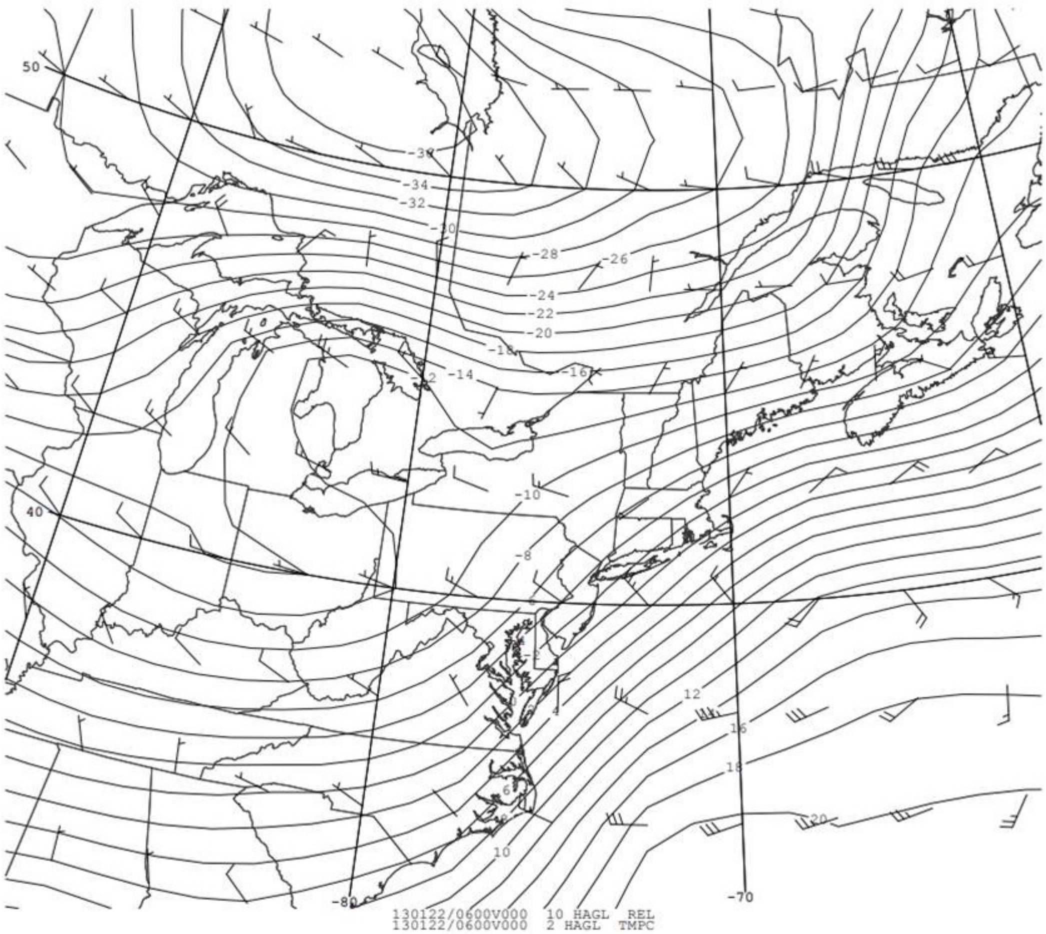

Figure 13: Analyzed surface temperature (contored in ^oC) and surface wind (vectors in kts) for the same time, as in January 22, 2013 at 06z.

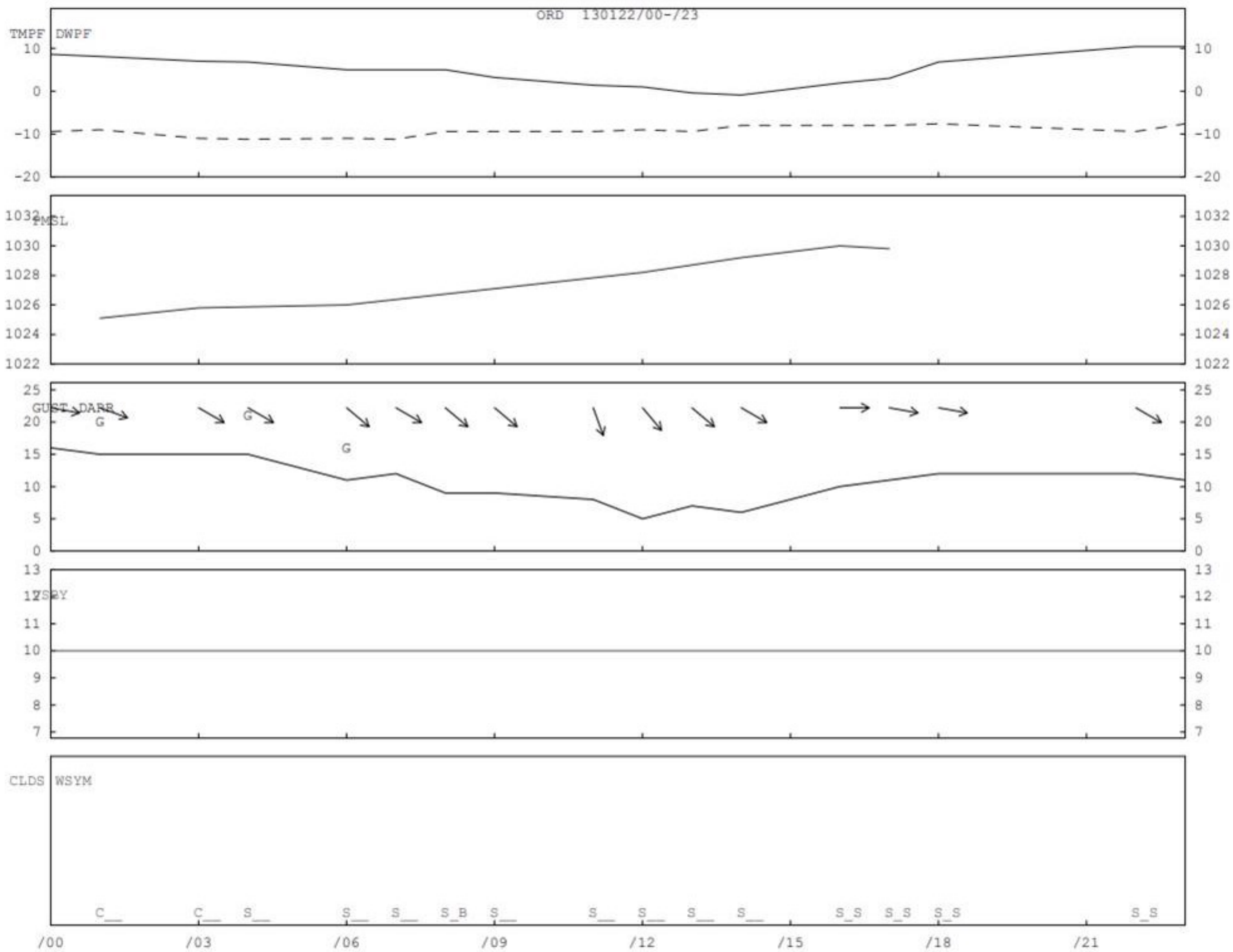

Figure 14: Surface meteogram for Chicago O'Hare (ORD) on January 22, 2013 showing temperature (continuous line) and dewpoint temperature (dashed line), surface pressure, wind speed and direction, visibility and cloud cover.

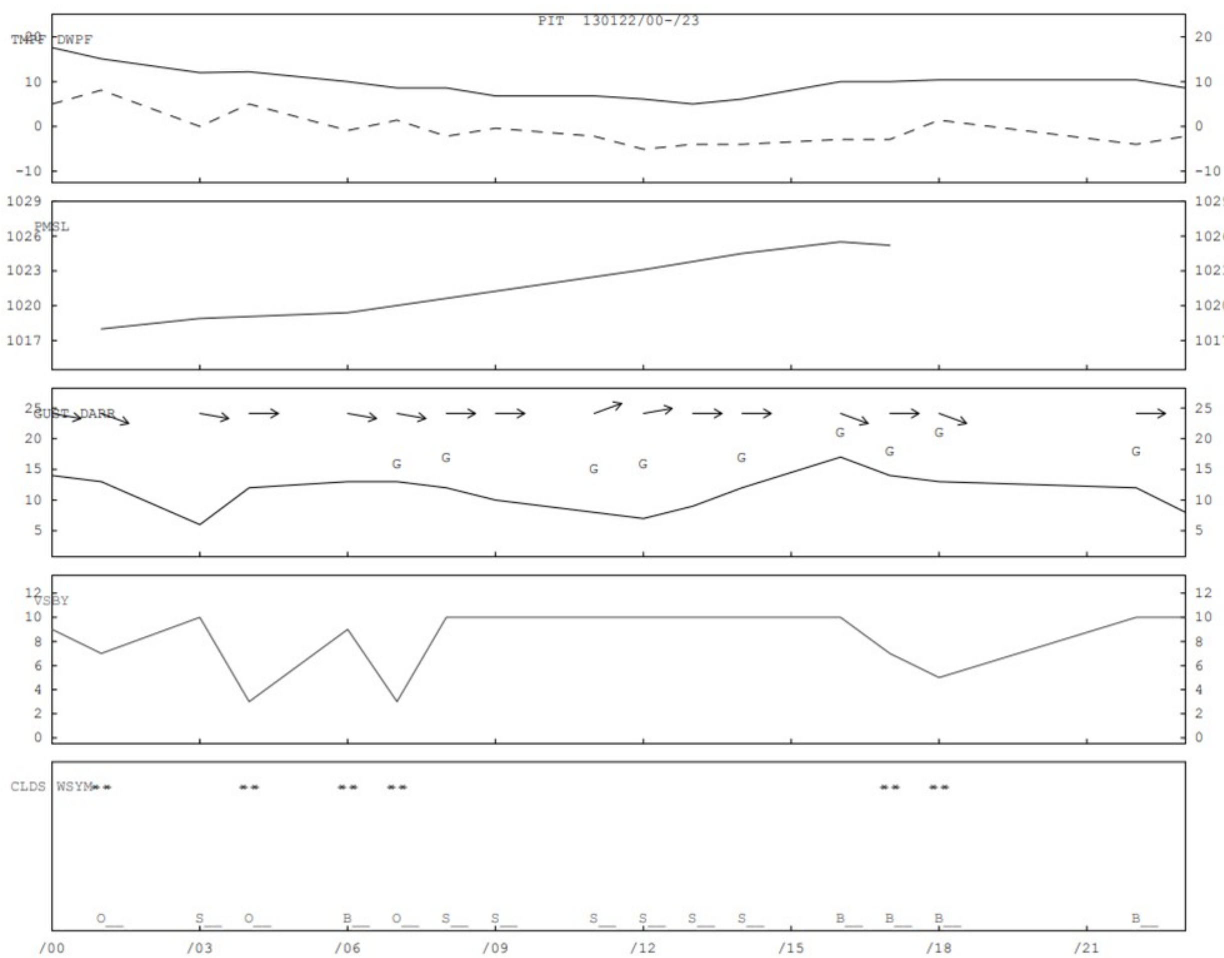

Figure 15: Surface meteogram for Pittsburg (PIT) on on January 22, 2013 showing temperature (continuous line) and dewpoint temperature (dashed line), surface pressure, wind speed and direction, visibility and cloud cover.