Lecture 2. August 24, 2016

Topics: Atmospheric variables. Vectors and scalars. Dimensions and units. Scales of atmospheric processes. Horizontal and vertical scales. Time scales.

Reading: Sections 1.1 to 1.3 of Holton and Hakim.

1. Atmospheric continuum

In atmospheric dynamics considerations, the atmosphere is regarded as continuous fluid medium. Notions of air parcel and air particle, interpreted as volume elements that are much smaller than the volume of the atmosphere under consideration, are broadly used in dynamic meteorology.

Atmospheric physical quantities are considered as space-and time-dependent field variables assumed to be continuous and uniquely defined functions of space and time. Space and time are usually taken as independent variables.

2. Units and dimensions of atmospheric variables

A *unit* in natural sciences is usually understood as a unit of measure (or measurement unit) that is used to quantify physical properties of different atmospheric components and phenomena, for instance – measures of their length, mass, time duration, and degree to which they are heated/cooled (temperature).

A (physical) *dimension* is a measurable extent of a physical property. In this respect, length, mass, time duration, and temperature are dimensions.

Base units

In modern atmospheric sciences, one mostly deals with international system of units (SI). *Base* SI units that are commonly used to represent dimensions of length, mass, time, and temperature for description of atmospheric properties are: **meter**, m (length); **kilogram**, kg (mass); **second**, s (time); **kelvin**, K (temperature).

Derived units

Derived SI units are formed from products and ratios of the base units. Examples of derived units with special names used in meteorology:

hertz, $\mathrm{Hz} = \mathrm{s}^{-1}$ (frequency);

newton, $\mathrm{N} = \mathrm{kg\ m\ s}^{-2}$ (force);

pascal, $\mathrm{Pa} = \mathrm{N\ m}^{-2} = \mathrm{kg\ m}^{-1}\ \mathrm{s}^{-2}$ (pressure);

joule, $\mathrm{J} = \mathrm{N\ m} = \mathrm{kg\ m}^{2}\ \mathrm{s}^{-2}$ (energy, work);

watt, $\mathrm{W} = \mathrm{J\ s}^{-1} = \mathrm{N\ m\ s}^{-1} = \mathrm{J\ Hz} = \mathrm{N\ m\ Hz}$ (power).

It is useful to know and remember prefixes associated with decimal multipliers (at least, from micro, 10^{-6}, to penta, 10^{15}).

3. Commonly used atmospheric variables and their units

Vectors and scalars

Vector is commonly defined as a geometric entity that represents a physical quantity endowed with magnitude and direction.

Scalar is a physical quantity which is independent of coordinate systems (in other words, a quantity that endowed with magnitude only).

Independent variables

Space/length (from microns, 10^{-6} m, to thousands of kilometers, 10^{6} m). In daily life in USA, UK, and several other countries the so-called ***Imperial units*** are also used: inch, foot, yard, mile.

Time [from microseconds, 10^{-6} s, to years, 60 seconds·× 60 minutes·× 24 hours·× 365(6) days].

Dependent variables

Temperature (scalar), also potential temperature and virtual potential temperature: **kelvin**, K. Other dimensions and units: degrees Celsius, ºC or simply C (TºC=T K – 273.15), degrees Fahrenheit [T F=(9/5)T C+32 or T F=(9/5)(T K – 273.15)+32].

Mass (scalar): kg. Also popular units are gram (10^{-3} kg) and ton (10^{3} kg). Another widely used (Imperial) unit is pound. **Note**: kilogram as measure of mass should not be confused with kilogram used as measure of weight (which is force).

Velocity (vector): length per unit time: m s^{-1}. Other commonly applied units are kilometer per hour and mile per hour (in the case of nautical mile per hour the velocity unit is usually called *knot*).

Momentum (vector), product of mass and velocity: kg m s^{-1}.

Acceleration (vector), velocity per unit time: m s^{-2}. Example is the gravitational acceleration vector. Commonly, only its negative vertical component taken with opposite sign, $g \approx 9.8$ m s^{-2}, is considered. It is an important atmospheric (quasi) constant.

Force (vector) is the product of mass and acceleration: **newton**, N= kg m s^{-2}. Can also be interpreted as momentum per unit time. **Note** that force is often (and rather confusingly) expressed in kilograms or pounds. In this case, the gravity force (weight) corresponding to the considered amount of kilograms (pounds) is usually meant.

Pressure (scalar), force per unit surface area: **pascal**, $\text{Pa} = \text{N m}^{-2}$. Usually atmospheric pressure is expressed in hectopascals, with 1hPa=100Pa. Also, **millibar** (mb), 1mb=1hPa, is widely used. Inches and millimeters of mercury column are still applied rather often.

Density (scalar), mass per unit volume: kg m^{-3}; the SI density unit does not have any special name.

Energy, *work* (scalar): **joule**, $\text{J} = \text{N m} = \text{kg m}^2\ \text{s}^{-2}$. Also (specifically, as a measure of heat energy) calories and kilocalories are often used. Another widespread unit is kilowatt-hour (kW h).

Power (scalar), energy per unit time: **watt**, $\text{W} = \text{J s}^{-1} = \text{N m s}^{-1} = \text{J Hz} = \text{N m Hz}$. Horsepower (Hp) is still often used as a measure of power in daily life: 1Hp≈0.75kW.

See unit conversion tables in textbooks and on the Internet.

4. Scales of atmospheric processes

In order to conduct the scaling analysis, typical expected values of independent and dependent atmospheric variables have to be specified. The following values are usually considered:

1. Magnitudes of the field variables (dependent variables).
2. Amplitudes of the fluctuations of the field variables.
3. Characteristic spatial (length, depth) and temporal scales on which the fluctuations of the field variables occur.

Scaling considerations and arguments are extensively used in the atmospheric dynamics to estimate the significance of particular atmospheric mechanisms and for simplification of governing equations of atmospheric processes.

For characteristic length scales of particular atmospheric phenomena see Table 1.4 in the textbook. It should be taken into account that spatial and time scales of atmospheric processes are in many cases related.

5. Orlanski system of horizontal atmospheric scales

Another classification of spatial (horizontal) scales of atmospheric processes is widely applied in meteorology. It was proposed by Isidoro Orlanski in the beginning of the 1960s. According to this classification (**note** that it has been many times updated and modified since it was introduced), the whole range of horizontal length scales of the atmospheric processes is subdivided in (the sign ~ means "of the order of"):

Global scales (~10^4 km=10^7 m).

Regional scales (from ~10^3 km=10^6 m to ~10^4 km=10^7 m).

Sometimes, the range of scales about 10^3 km is referred to as *synoptic* scale range.

Mesoscales (from ~10^0 km=1km=10^3 m to ~10^3 km=10^6 m);

α-mesoscale range (from ~10^2 km=10^5 m to ~10^3 km=10^6 m),

β-mesoscale range (from ~10^1 km=10^4 m to ~10^2 km=10^5 m), *γ-mesoscale* range (from ~10^0 km=10^3 m to ~10^1 km=10^4 m);

Sometimes, the range of scales from ~0.1km=10^2 m to ~10^0 km=10^3 m is called the *submeso* scale range.

Microscales (up to ~10^0 km=1km=10^3 m).

6. Vertical atmospheric scales

Distances considered below are measured from the Earth's surface (ground) level!

Atmosphere (more than ~10 km=10^4 m)

Troposphere (less than ~10 km=10^4 m).

Atmospheric planetary boundary layer (ABL or PBL; usually specified as a portion of the lower atmosphere directly affected by the interactions between the atmosphere and the Earth's surface): from ~0.1km=100m to ~1 km=10^3 m.

Atmospheric surface layer (ASL; usually specified as an atmospheric layer adjacent to the surface where turbulent fluxes of mass, momentum, and heat may be considered constant with height): from ~1m to ~10m.

Laminar layer (also called the *viscous sublayer*) in the immediate vicinity of the surface, which should be smooth enough for the laminar layer concept to be valid: from ~10^{-4} m=0.1mm to ~10^{-2} m=1cm.

Note that, depending on the properties of the underlying surface, the stage of diurnal evolution, and the character of the atmosphere-surface interaction, other (sub)layers are commonly considered within the atmospheric planetary boundary layer: entrainment layer, residual layer, roughness layer, radix layer, inertial layer, canopy layer, logarithmic layer, mechanical turbulence layer. This is not the complete list, though…

7. Time scales of atmospheric processes

Molecular motion: from microseconds to fraction of a second.

Small-scale surface-layer turbulence: seconds to minutes.

Dust devils: minutes.

Coherent structures in the atmospheric convective boundary layer (convective plumes and thermals): from minutes to tens of minutes.

Tornado: from minutes to tens of minutes.

Atmospheric fronts: from minutes to hours.

Cumulus clouds, *convective supercells*, *thunderstorms*: from tens of minutes to hours.

Cyclones, *hurricanes*: from several hours to few days.

Synoptic time scale: several days (week).

Anticyclones: several days (week).

Jet stream: weeks.

Diurnal variations: 24 hours (day).

Seasonal variations: three months.

Annual variations: year [365(6) days].

Climate changes: tens of years and more.

Note that most atmospheric phenomena are essentially characterized by more than one time scale.