Atmospheric modeling basics

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Numerical weather prediction in basic form

ΔA = the change in a forecast variable at a particular point in space

$$\frac{\Delta A}{\Delta t} = F(A)$$

F(A) describes the physical processes that can cause changes in the value of A

Δt equals the change in time

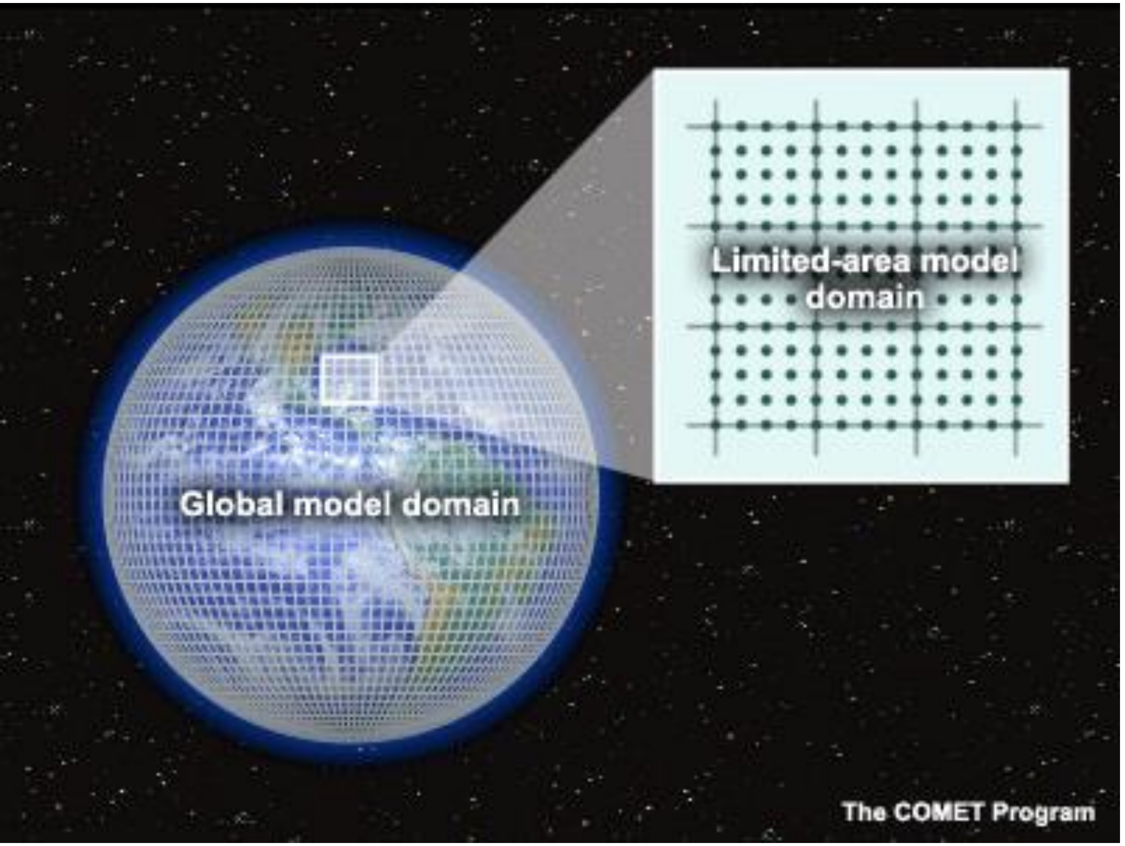
Future weather variables are solved by using initial values and then adding contributions from physical processes over a short period of time

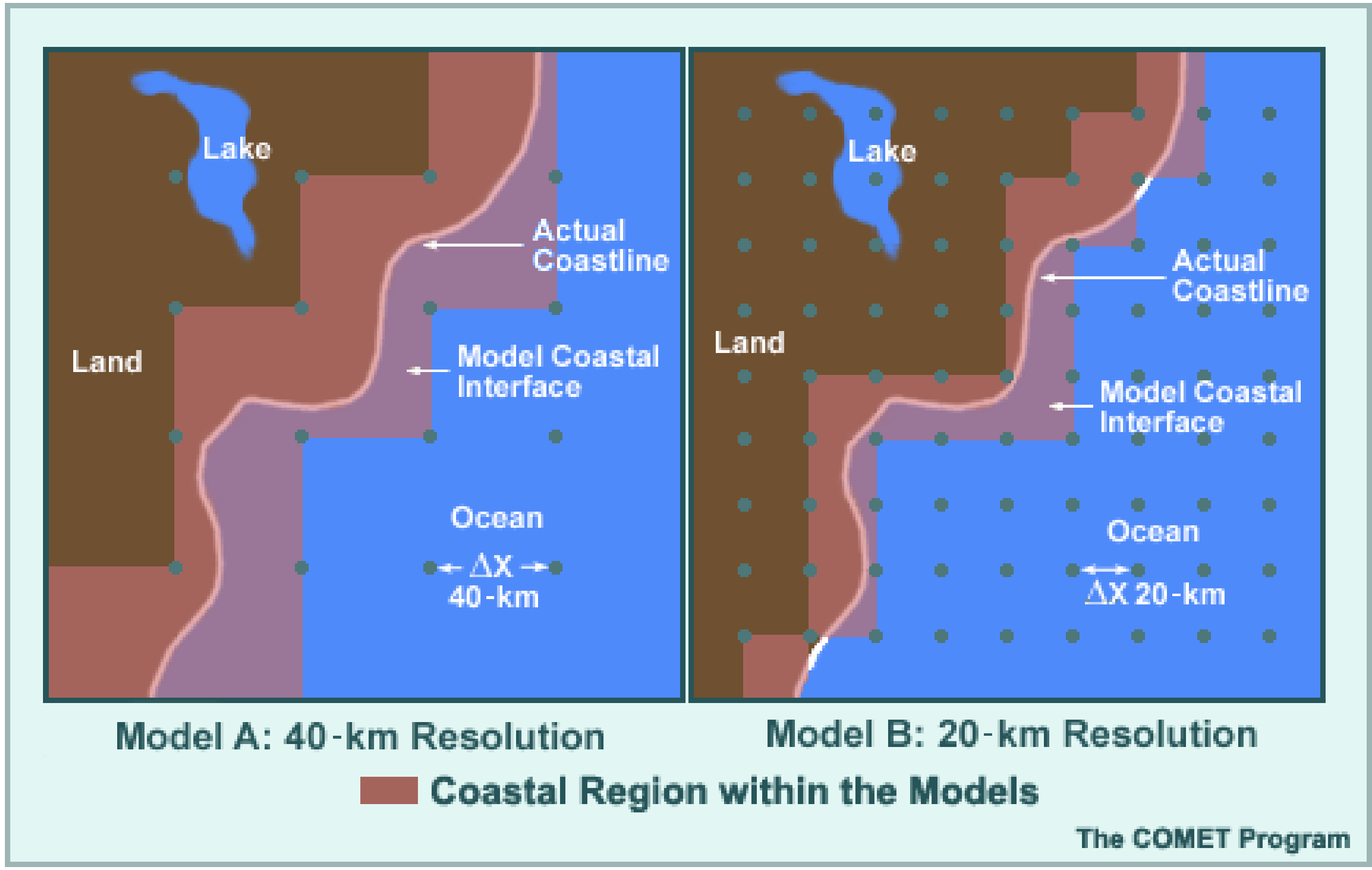
$$A^{forecast} = A^{initial} + F(A)\,\Delta t$$

Δt could be, for example, five minutes. Then, the predicted value replaces $A^{initial}$ Another five minute prediction is made. This process is repeated out to, for example, 48 hours.

This is essentially how forecasts are made. The same applies to ocean, wave, and storm surge models. The math, equations, numerical method techniques, and computer software are very complicated, however.

The equations are solved on a grid like these. Resolution is very important.





Higher resolution yields better forecasts. It is constrained by computer power, a lack of observations, and unknowns regarding small-scale physical processes.

Ultimately, there are also predictability limits. New techniques use ensembles to better understand where the forecasts errors are, and to apply a probability rather than a "single number."

Students need to learn calculus

Wind Forecast Equations

1a. $$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - \omega\frac{\partial u}{\partial p} + fv - g\frac{\partial z}{\partial x} + F_x$$

1b. $$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - \omega\frac{\partial v}{\partial p} - fu - g\frac{\partial z}{\partial y} + F_y$$

Continuity Equation

2. $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0$$

Temperature Forecast Equation

3. $$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - \omega\left(\frac{\partial T}{\partial p} - \frac{RT}{c_p p}\right) + \frac{H}{c_p}$$

Moisture Forecast Equation

4. $$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - \omega\frac{\partial q}{\partial p} + E - P$$

Hydrostatic Equation

5. $$\frac{\partial z}{\partial p} = -\frac{RT}{pg}$$

$$\underbrace{\frac{\partial u}{\partial t}}_{\substack{\text{Time changes in the}\\ \text{west - to - east wind}}} = \underbrace{- u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y}}_{\substack{\text{Horizontal advection of}\\ \text{the west - to - east wind}\\ \text{(momentum)}}} \underbrace{- \omega\frac{\partial u}{\partial p}}_{\substack{\text{Vertical advection of}\\ \text{the west - to - east wind}\\ \text{(momentum)}}} + \overbrace{fv - g\frac{\partial z}{\partial x}}^{\substack{\text{Deviations from}\\ \text{geostrophic balance for}\\ \text{the south - to - north wind}}} + \underbrace{F_x}_{\substack{\text{Surface friction}\\ \text{and turbulent mixing}\\ \text{acting on the west -}\\ \text{to - east wind}}}$$

$$\underbrace{\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}}_{\substack{\text{Horizontal}\\ \text{Divergence}}} + \underbrace{\frac{\partial \omega}{\partial p}}_{\substack{\text{Vertical}\\ \text{Divergence}}} = 0$$

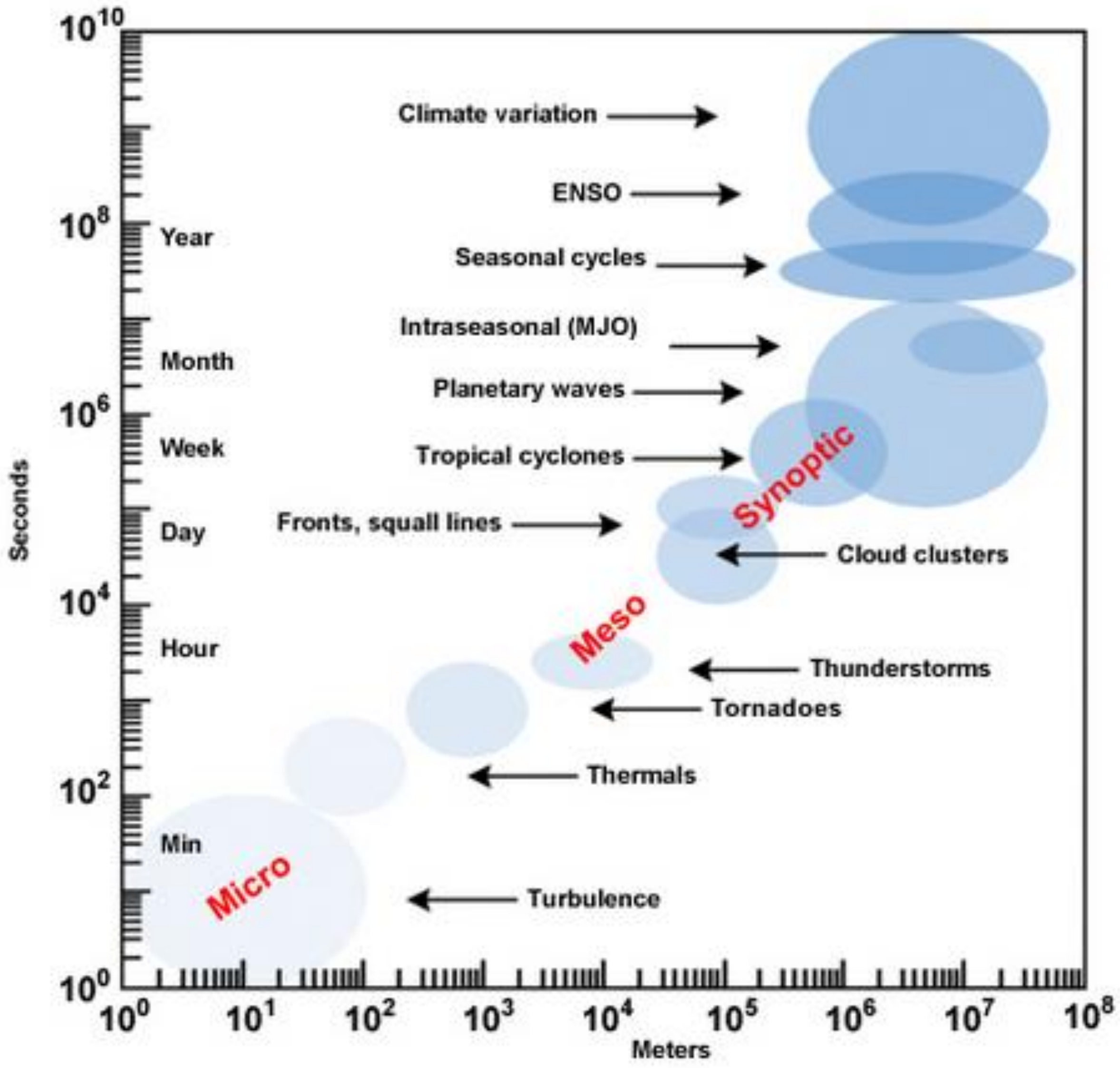
$$\underbrace{\frac{\partial T}{\partial t}}_{\substack{\text{Time changes}\\ \text{in temperature}}} = \underbrace{- u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y}}_{\substack{\text{Horizontal advection}\\ \text{of temperature}}} \underbrace{- \omega\left(\frac{\partial T}{\partial p} - \frac{RT}{c_p p}\right)}_{\substack{\text{Difference between}\\ \text{vertical temperature}\\ \text{advection \& adiabatic}\\ \text{processes}}} + \frac{\overbrace{H}^{\substack{\text{Other processes}\\ \text{(i.e., radiation, mixing,}\\ \text{and condensation)}}}}{c_p}$$

$$\underbrace{\frac{\partial q}{\partial t}}_{\substack{\text{Time changes}\\ \text{in moisture}}} = \underbrace{- u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y}}_{\substack{\text{Horizontal advection}\\ \text{of moisture}}} \underbrace{- \omega\frac{\partial q}{\partial p}}_{\substack{\text{Vertical advection}\\ \text{of moisture}}} + \overbrace{E}^{\substack{\text{Evaporation}\\ \text{and sublimation}}} - \underbrace{P}_{\substack{\text{Condensation}\\ \text{(Precipitation)}}}$$

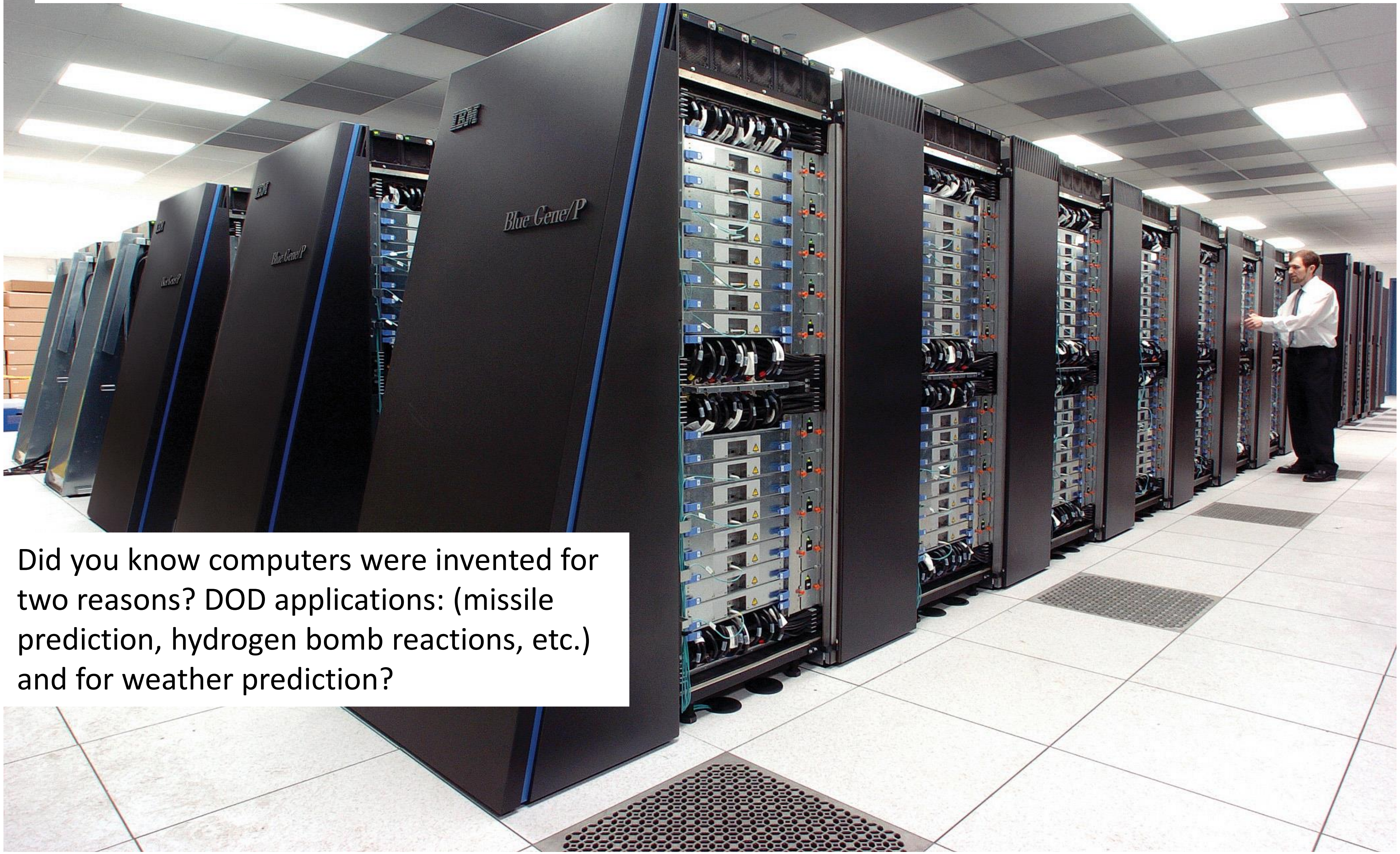
$$\frac{\overbrace{\partial z}^{\substack{\text{Difference in height}\\ \text{between upper \& lower}\\ \text{isobaric sufaces}}}}{\partial p} = - \underbrace{\frac{RT}{pg}}_{\substack{\text{Mean temperature}\\ \text{within a layer}}}$$

Atmospheric Scales

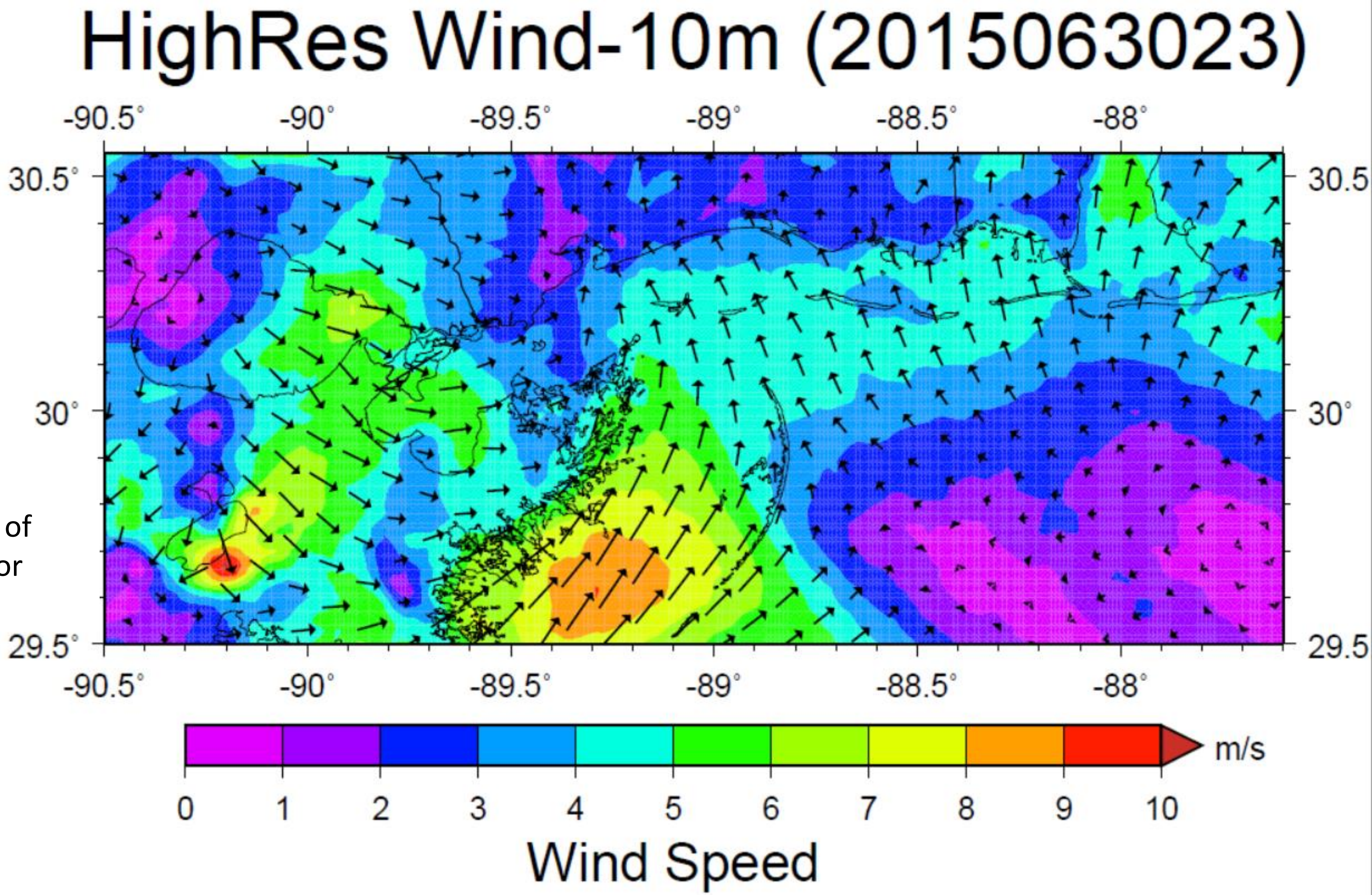
Equations vary
for different scales.



Typical supercomputer



Did you know computers were invented for two reasons? DOD applications: (missile prediction, hydrogen bomb reactions, etc.) and for weather prediction?



Example output of modeled wind for CONCORDE