Atmospheric modeling basics

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Numerical weather prediction in basic form

\[ \frac{\Delta A}{\Delta t} = F(A) \]

\( \Delta t \) equals the change in time.

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

Future weather variables are solved by using initial values and then adding contributions from physical processes over a short period of time. \( \Delta t \) could be, for example, five minutes. Then, the predicted value replaces \( A_{\text{initial}} \). 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. \[ \frac{\partial T}{\partial t} = -u \frac{\partial T}{\partial x} - v \frac{\partial T}{\partial y} - \omega \left( \frac{\partial T}{\partial p} - \frac{RT}{cp} \right) + \frac{H}{cp} \]

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. \[ \frac{\partial z}{\partial p} = -\frac{RT}{pg} \]
Deviations from geostrophic balance for the south-to-north wind:

\[ \frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - \frac{\partial u}{\partial p} + f v - g \frac{\partial z}{\partial x} + F_x \]

- Time changes in the west-to-east wind
- Horizontal advection of the west-to-east wind (momentum)
- Vertical advection of the west-to-east wind (momentum)
- Surface friction and turbulent mixing acting on the west-to-east wind

Other processes (i.e., radiation, mixing, and condensation):

\[ \frac{\partial T}{\partial t} = -u \frac{\partial T}{\partial x} - v \frac{\partial T}{\partial y} - \frac{\partial T}{\partial p} - \left( \frac{\partial T}{\partial p} \frac{R}{c_p} \right) + \frac{H}{c_p} \]

- Time changes in temperature
- Horizontal advection of temperature
- Vertical advection of temperature

Difference in height between upper & lower isobaric surfaces:

\[ \frac{\partial z}{\partial p} = - \frac{RT}{\rho g} \]

- Mean temperature within a layer

Evaporation and sublimation:

\[ \frac{\partial q}{\partial t} = -u \frac{\partial q}{\partial x} - v \frac{\partial q}{\partial y} - \frac{\partial q}{\partial p} + E - P \]

- Time changes in moisture
- Horizontal advection of moisture
- Vertical advection of moisture
- Condensation (Precipitation)
Equations vary for different scales.
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