Using Climate Models to study Atmospheric Waves

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Image credit Roger McLassus, wikimedia commons
What ARE Atmospheric Waves?

Image credit Brocken Inaglory, wikimedia commons
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Waves need a restoring force – usually gravity
What ARE Atmospheric Waves?

Waves need a restoring force – often gravity
Atmospheric lee waves

Image credit: NASA
Atmospheric lee waves

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Atmospheric lee waves
Atmospheric lee waves

Image credit: NASA
Lenticular clouds
Dust gravity waves

Image credit: NASA
Why do we care about Atmospheric Waves?

1. They look awesome.

Image credit: Alpsdake, Wikimedia commons
Why do we care about Atmospheric Waves?

2. They affect how comfortable airplane flights are

Image credit: CNN
Why do we care about Atmospheric Waves?

- Often pilots know where turbulence is – they can see the waves in the clouds
- But what if there is not enough water vapor for clouds to form?

If an atmospheric wave forms, but there are no clouds around to see it .... does it exist?
Why do we care about Atmospheric Waves?
Why do we care about Atmospheric Waves?

Intensification of winter transatlantic aviation turbulence in response to climate change

Paul D. Williams & Manoj M. Joshi

Nature Climate Change 3, 644–648 (2013) | doi:10.1038/nclimate1866
Received 12 November 2012 | Accepted 05 March 2013 | Published online 08 April 2013
Why do we care about Atmospheric Waves?

3. Breaking waves transfer energy

Image credit Brocken Inaglory, wikimedia commons
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3. Breaking waves transfer energy

Image credit Brocken Inaglory, wikimedia commons
Why do we care about Atmospheric Waves?

- The energy transfer from the breaking of large scale atmospheric waves can have very far-reaching effects.
Why do we care about Atmospheric Waves?

The energy transfer from the breaking of large scale atmospheric waves can have very far-reaching effects.
Why do we care about Atmospheric Waves?

4. Waves can travel globally and affect temperatures worldwide

Tropical forcing of the recent rapid Arctic warming in northeastern Canada and Greenland

Qinghua Ding, John M. Wallace, David S. Battisti, Eric J. Steig, Ailie J. E. Gallant, Hyung-Jin Kim & Lei Geng

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Nature 509, 209–212 (08 May 2014) | doi:10.1038/nature13260
Received 19 October 2013 | Accepted 12 March 2014 | Published online 07 May 2014
Why do we care about Atmospheric Waves?

4. Waves can travel globally and affect temperatures worldwide
Why do we care about Atmospheric Waves?

5. Waves affect phenomena that impact our weather
   - Planetary scale Rossby waves – the jet and storm tracks
Rossby Waves

- Because we live on a spherical, rotating planet
- Restoring force is not gravity (it’s essentially the conservation of angular momentum, but on a rotating sphere)

Image credit: NASA, eumetcal.org
Why do we care about Atmospheric Waves?

5. Waves affect phenomena that impact our weather
   - El Nino Southern Oscillation
Why do we care about Atmospheric Waves?

5. Waves affect phenomena that impact our weather.

Animation credit NASA, JPL
Why do we care about Atmospheric Waves?

5. Waves also affect phenomena that impact our weather
   - E.g. El Nino Southern Oscillation
   - E.g. Madden-Julian Oscillation – patterns of rainfall in the Indian ocean, Maritime continent and Western Pacific ocean

Image credit: UCAR
Using Climate Models to study Atmospheric Waves

Image credit Roger McLassus, wikimedia commons
What is a Climate Model?
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What is a Climate Model?

\[
\frac{\partial}{\partial t} u = \Omega v - \frac{1}{A \cos \theta} \left[ \frac{\partial}{\partial \lambda} \left( \kappa + \Phi - \nu D \right) + \frac{1}{\rho} \frac{\partial}{\partial \lambda} \rho \right] - \frac{d \zeta}{dt} \frac{\partial u}{\partial \zeta},
\]

(3.6)

\[
\frac{\partial}{\partial t} v = -\Omega u - \frac{1}{A} \left[ \frac{\partial}{\partial \theta} \left( \kappa + \Phi - \nu D \right) + \frac{1}{\rho} \frac{\partial}{\partial \theta} \rho \right] - \frac{d \zeta}{dt} \frac{\partial v}{\partial \zeta},
\]

(3.7)
What is a Climate Model?

\[ \omega = \mathbf{V} \cdot \nabla p - \int_{\eta_t}^{\eta} \nabla \cdot \left( \frac{\partial p}{\partial \eta} \mathbf{V} \right) d\eta. \]
What is a Climate Model?

\[
\rho_o C_o h_o \frac{\partial T_o}{\partial t} = (1 - A) F + Q + A F_{oi} + (1 - A) F_{frz}
\]
Adding land vs sea

\[ \tau_x = -\rho_1 \overline{w w'} = -\rho_1 u_s^2 (u_1 / V_o) = \rho_1 \frac{u_s - u_1}{r_{am}} \]
Adding land type

\[ F_{\psi_T} = a_i F_{\psi_i} + a_o F_{\psi_o} + a_l F_{\psi_l} , \]

\[ \overline{w'C'} = -K_c \left( \frac{\partial C}{\partial z} - \gamma_c \right) \]
Adding land height (topography)

\[
\frac{\partial}{\partial t} (u, v, q) = -\frac{1}{\rho} \frac{\partial}{\partial z} (F_u, F_v, F_q)
\]

\[
\frac{\partial}{\partial t} s = -\frac{1}{\rho} \frac{\partial}{\partial z} F_H + D
\]
What is a Climate Model?

Horizontal Grid (Latitude-Longitude)

Vertical Grid (Height or Pressure)

Physical Processes in a Model

1. Solar radiation
2. Terrestrial radiation
3. Water
4. Snow
5. Momentum
6. Heat
7. Sea ice
8. Mixed layer ocean

Advection
Improving Resolution
<table>
<thead>
<tr>
<th>Observed</th>
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Comparison with observations
Playing with Climate Models

- Add CO₂ to the atmosphere
- Move continents around - paleoclimates
- Remove mountains
- Change land use (e.g. deforestation)
- Add freshwater to the North Atlantic (effect of Greenland melting)
- Change ocean – fixed sea surface temperatures
  - Change the sea surface temperature
The effects of mountains on Rossby waves
The effects of mountains on Rossby waves
The effects of mountains on the jet stream
Closing the gap between Europe and the US...
Closing the gap between Europe and the US...
Deforesting the tropical rainforests: albedo
Deforesting the tropical rainforests: surface T
Summary

Waves exist in the atmosphere, even when there aren’t clouds or dust to see them in.

They look awesome, but also impact our weather and climate (and airplane flights).

Waves transfer energy:
Sudden stratospheric warmings, ENSO, Tropical SSTs affecting the pole.

Climate models can be used to study atmospheric waves and their impacts.