MET 600: Advanced Atmospheric Dynamics

Energy Conservation:
\[
\frac{\partial T}{\partial t} = -u \frac{\partial T}{\partial x} - v \frac{\partial T}{\partial y} + \omega \left( \frac{RT}{c_p p} - \frac{\partial T}{\partial p} \right) + \frac{H}{c_p}
\]

Moisture Conservation: e.g., Hydrological cycle
\[
\frac{\partial q}{\partial t} = -u \frac{\partial q}{\partial x} - v \frac{\partial q}{\partial y} - \omega \frac{\partial q}{\partial p} + E - P
\]

Mass Conservation: e.g., CO₂ cycle
\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial p} = 0
\]

Momentum Conservation:
\[
\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial x} - v \frac{\partial u}{\partial y} - \omega \frac{\partial u}{\partial p} + fv - \frac{\partial \phi}{\partial x} + F_x
\]
\[
\frac{\partial v}{\partial t} = -u \frac{\partial v}{\partial x} - v \frac{\partial v}{\partial y} - \omega \frac{\partial v}{\partial p} - fu - \frac{\partial \phi}{\partial y} + F_y
\]

Air-sea interface
Energy/Salinity/Mass/Momentum Conservations
万物生长靠太阳

It is the sun that sustains all living beings on earth

And God said, "Let there be light," and there was light.  Genesis 1:3
Energy Conservation:
Global Radiation Balance

How the atmosphere-ocean-land system is driven?
How the atmosphere-ocean-land system is driven?
How the atmosphere-ocean-land system is driven?
The Earth receives a total amount of radiation determined by its cross section \((\pi \cdot R_E^2)\), but as it rotates, this energy is distributed across the entire surface area \((4 \cdot \pi \cdot R_E^2)\).

So, the incident solar radiation at the top of the atmosphere (TOA) per unit area of the earth’s surface is: \(\frac{1}{4} S = 340 \text{ W m}^{-2}\)
Seasonal variations of TOP solar radiation

How the atmosphere-ocean-land system is driven?
Albedos of various earth surfaces

Oke 1992; Ahrens 2006

How the atmosphere-ocean-land system is driven?
How the atmosphere-ocean-land system is driven?
Seasonal changes of planetary albedo

How the atmosphere-ocean-land system is driven?
Solar Radiation and Outgoing Longwave Radiation (OLR)

How the atmosphere-ocean-land system is driven?
Conceptual Global Energy Balance

How the atmosphere-ocean-land system is driven?
Latest Global Energy Balance

Wild et al. 2013

How the atmosphere-ocean-land system is driven?
How the atmosphere-ocean-land system is driven?
Model Biases: overestimated downward solar radiation

How the atmosphere-ocean-land system is driven?
Model Biases: underestimated downward longwave radiation

How the atmosphere-ocean-land system is driven?
Global Climate Change: Greenhouse Effect
Greenhouse Effect

Outgoing heat is absorbed by greenhouse gas molecules and re-emitted in all directions, warming the surface of the earth and the lower atmosphere.
Increasing greenhouse gases

How the atmosphere-ocean-land system is driven?
Observed climate changes

How the atmosphere-ocean-land system is driven?
Observed global warming

(b) Observed change in surface temperature 1901–2012

How the atmosphere-ocean-land system is driven?
Observed tropospheric warming vs. Stratosphere cooling

How the atmosphere-ocean-land system is driven?
Long-term precipitation time series
Atmosphere-Ocean Exchange

How the atmosphere-ocean-land system is driven?
Air-sea exchange processes

How the atmosphere-ocean-land system is driven?
Net surface solar radiation

Positive: downward

How the atmosphere-ocean-land system is driven?
Net surface longwave radiation

Positive: downward

How the atmosphere-ocean-land system is driven?
Surface latent heat flux

Positive: downward

How the atmosphere-ocean-land system is driven?
Surface sensible heat flux

Positive: downward

How the atmosphere-ocean-land system is driven?
Net surface heat flux

Positive: downward

How the atmosphere-ocean-land system is driven?
Surface winds

How the atmosphere-ocean-land system is driven?
Upper-Ocean Currents

How the atmosphere-ocean-land system is driven?
Ocean surface CO$_2$ flux

How the atmosphere-ocean-land system is driven?
Moisture Conservation: Hydrological Cycle

How the atmosphere-ocean-land system is driven?
How the atmosphere-ocean-land system is driven?
Earth's Hydrologic Cycle

Reservoirs (boxes) in $10^{15}$ kg; fluxes (arrows) in $10^{15}$ kg/yr

- Continental Atmosphere: 4.5
- Maritime atmosphere: 11
- Evaporation: 434
- Precipitation: 398
- Advection: 36
- Evaporation and transpiration: 71
- Precipitation: 107
- River Runoff: 36
- Land:
  - ice and snow: 43400
  - surface water: 360
  - underground water: 15300
  - biota: 2
- Oceans:
  - mixed layer: 50000
  - thermocline: 460000
  - abyssal: 890000
- 59000

Adapted from: Chahine (1992), Nature, 359, p 373, figure 1.

How the atmosphere-ocean-land system is driven?
Effects of Horizontal Gradients: Hadley Cell & Heat Transport

How the atmosphere-ocean-land system is driven?
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How the atmosphere-ocean-land system is driven?
Annual mean precipitation

How the atmosphere-ocean-land system is driven?
Hadley Circulations

How the atmosphere-ocean-land system is driven?
Meridional heat transport

How the atmosphere-ocean-land system is driven?
Northward heat transport

Oceanic transport

Atmospheric transport

How the atmosphere-ocean-land system is driven?
Vertically-averaged Transient Meridional Heat Flux (100-1000 mb)

How the atmosphere-ocean-land system is driven?
Northward Heat Transport by Gulf Stream

How the atmosphere-ocean-land system is driven?
**MET 600: Advanced Atmospheric Dynamics**

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**Air-sea interface**

**Energy/Salinity/Mass/Momentum Conservations**
How the atmosphere-ocean-land system is driven?
Observed Incident Solar Radiation

How the atmosphere-ocean-land system is driven?

Kopp and Lean 2011