Atmospheric Heat Transport
Estimations Based on Satellite and Assimilation Data

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• Introduction: energy cycle for climate
  - climate heat balance
  - interact with water cycle
  - previous efforts: observation & assimilation
• Energy balance: TOA, sfc, atm.
  - radiation & turbulence ↔ precipitation
  - land surface fluxes
  - Global, zonal and regional annual means
  - energy & water balance
• Summary
Introduction

- **Energy imbalance**: a fundamental process: related directly to climate sensitivity and ocean heat storage

- Entwined with water cycles – E and P

- Observations + assimilations: global/large scale balances, variability, atmospheric & ocean heat transports

lack: land/cold regions, light rains

errors: divergence calculation, model errors
Estimation Approaches

• Land surface fluxes: assimilations
  heat storage \((S)\), Bowen ratio

  \[
  R_{\text{net}} = LH + SH + S \quad (1)
  \]

  \[
  B = \frac{LH}{LH+SH} \quad (2)
  \]

  ◆ negligible land horizontal heat transport
  ◆ forced by surface net radiative fluxes

• Net radiation: satellite observations
  TOA, surface, within atmosphere
Estimation Approaches

- **Atmospheric heat flux transports:**
  - **Moist static energy:**
    - sensible heat, latent heat, geopotential energy
  - Kinetic energy: air movements

- **Assuming no horizontal net radiation transports in large/long-term scales & no horizontal heat transports over land**
Net radiation (annual mean)

Local heat balance: latent & sensible heat, transport
Zonal heat transports: heat balance from TOA net radiation
other heat forms than radiation from atmosphere & ocean
sfc turbulent fluxes

Latent heat

Sensible heat

Annual Mean
Ocean surface heat budget

Annual mean sea surface heat budget (W/m²). Positive values indicate that oceans gain heat from the atmosphere. Assuming minimal vertical heat transports, large horizontal heat transports can be seen here.
Poleward Ocean Heat Transport

Latitude (°N)

Zonal heat transport (PW)

88-00 Mean Transport from FD/SRB & GSSTF/HOAPS/WHOI W/ Min/max

Zhang et al. JGR 2002
Heat transports by dynamics & thermodynamics

- Atmospheric heat flux transports:
  moist static energy
  \[ E_m = C_p T + L q + g z \]
  Kinetic energy
  \[ E_k = \frac{||V||^2}{2} \]
  for unit mass
  \[ \Delta E = \nabla \cdot EV \rightarrow \text{in zonal or regional scale} \]

- Mostly for Lq term
Zonal latent heat divergence

ITCZ: very weak winds & potential large divergence errors
Regional Atmos. Net Radiation

(-113 ± 0.97 W/m²)

Mediterranean -120.35 (1.50)  Caribbean -125.61 (1.57)  Black Sea -110.43 (2.07)
sfc turbulent fluxes

Ocean: HOAPS
Land: GLDAS

sensible heat
(18 ± 1.9 W/m²)

latent heat
(82.2 ± 2.5 W/m²)
### Regionaal radiative and other heat fluxes (W/m²)

<table>
<thead>
<tr>
<th>Region</th>
<th>TOA</th>
<th>SFC</th>
<th>ATMO</th>
<th>Latent</th>
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EBAF, HOAPS, Princeton (latent), MOSIC (sensible), and GMAO (div) 2001-2005
Summary

- Satellite observations and assimilation results provide certain insights for the global heat transports. However, certain heat fluxes and transports may not be available, especially those for cold region processes.

- The errors in annual global energy balance are within the systematic error range of radiation estimations. Progress in satellite observations of radiation and sea surface turbulent fluxes significantly reduces the uncertainties in annual mean energy budgets.
Summary (conti.)

- Zonal total poleward heat transports vary from -6PW to +6PW with peak values around 30° to 35° latitudes. The errors and uncertainties are limited by the accuracy of current satellite TOA observations.

- Although certain differences among global satellite estimates of oceanic heat transports exist, the larger errors are among atmospheric heat transports. Analysis finds general agreements of zonal & regional latent heat transport between E-P and water vapor transports. Moisture divergence is the key in estimations.
Thank You!