EBM and beyond

0d EBM

$$c_p \frac{dT}{dt} = (1-\alpha)\frac{S}{4} - \varepsilon\sigma T^4$$

- What is the temperature of the Earth?
- (choices for parameters)
- Time step … issues?

- *Able to predict mean/stable/steady state OK, but what about change?*
- *Can we predict/model all we need to know? (i.e., given hindsight is the scope appropriate for our science question?)*

Discussion

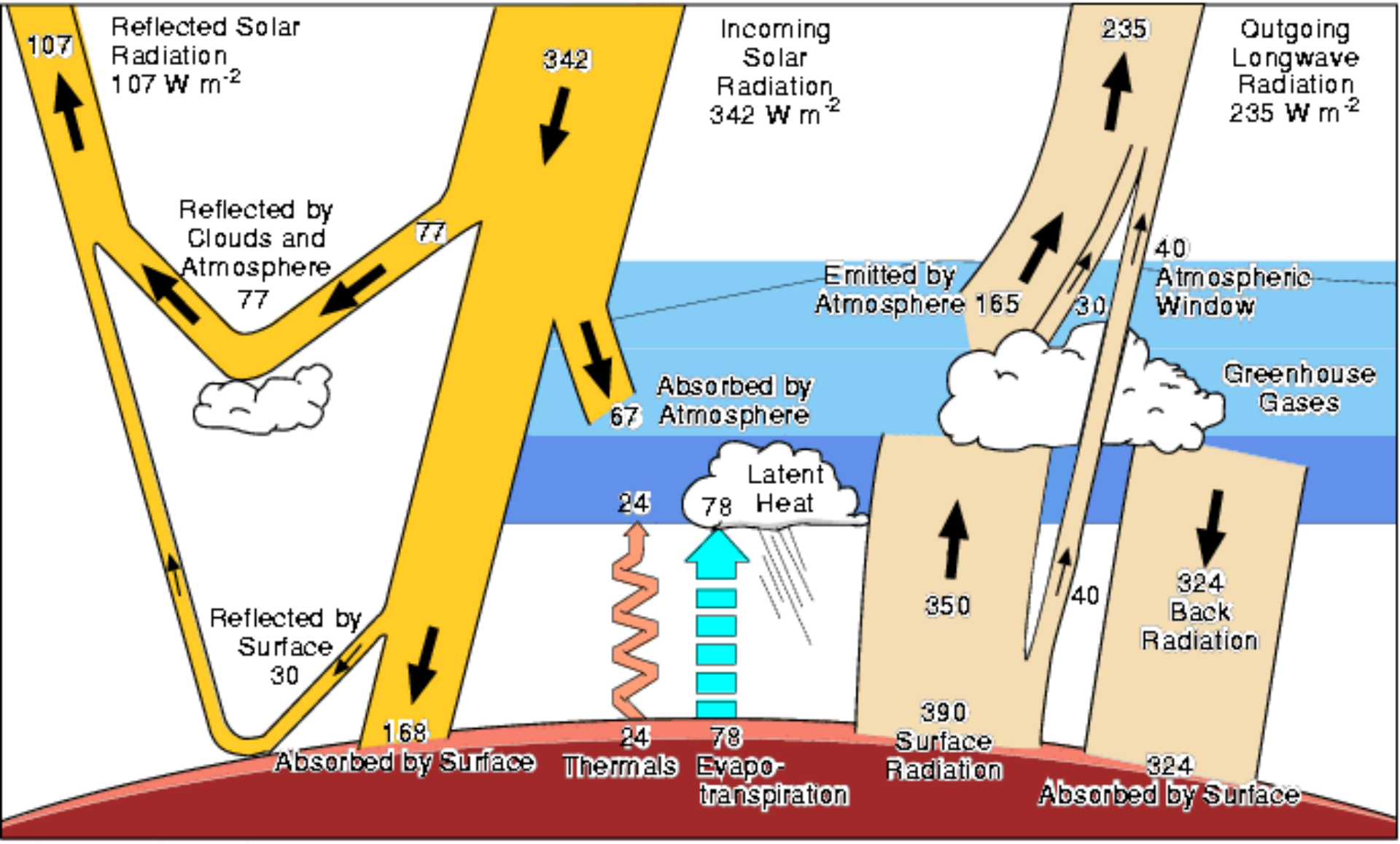
- What is the radiative equilibrium temperature of Earth?
- How does this depend on the choice of the time step?
- Change the heat capacity so as to model the upper 70 meters of the ocean rather than the atmosphere. Does the equilibrium temperature change?
- Is the mean temperature the same if there is a diurnal cycle? Annual cycle? “Glacial” cycle?
- If the sun should stop, how long does it take for the temperature to become a factor of e^{-1} its equilibrium value (i.e., what is the e-folding time), for both the atmosphere and upper ocean?
- How can the e-folding time be found analytically from (1)?
- How would you construct a coupled atmosphere-ocean model with this level of complexity?
- What are some limitations of this model, and what are their consequences?

What did (didn’t) we gain

- Same balanced solution as analytical form
- Gain time dependent behavior
- Could not model greenhouse effect

- Can we answer the science question? (can we do hypothesis testing?)

Global Heat Flows



Each flux (arrow) changes energy of the atmosphere/climate system

Kiehl and Trenberth 1997

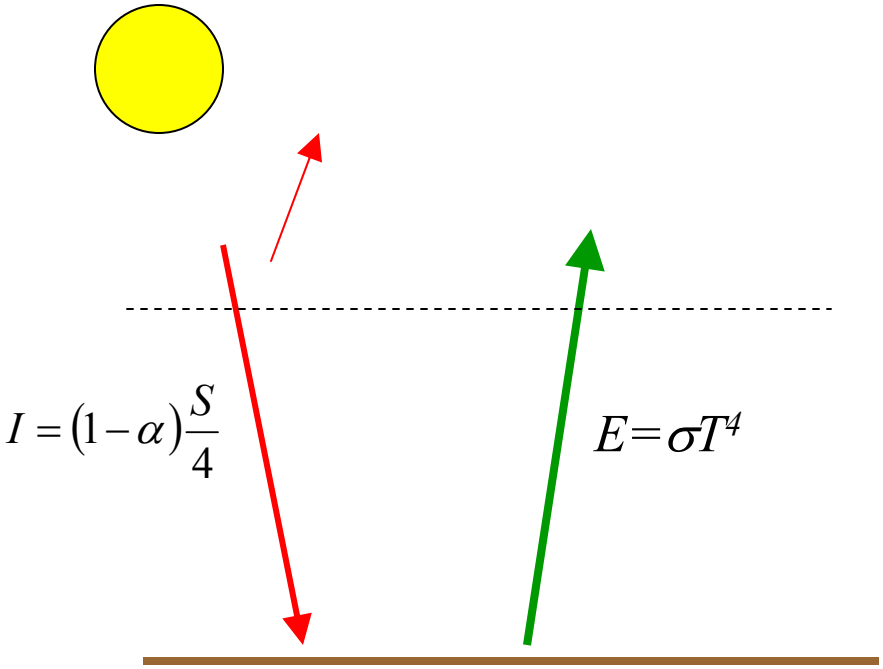
A look at forward difference

Formal (almost) origin

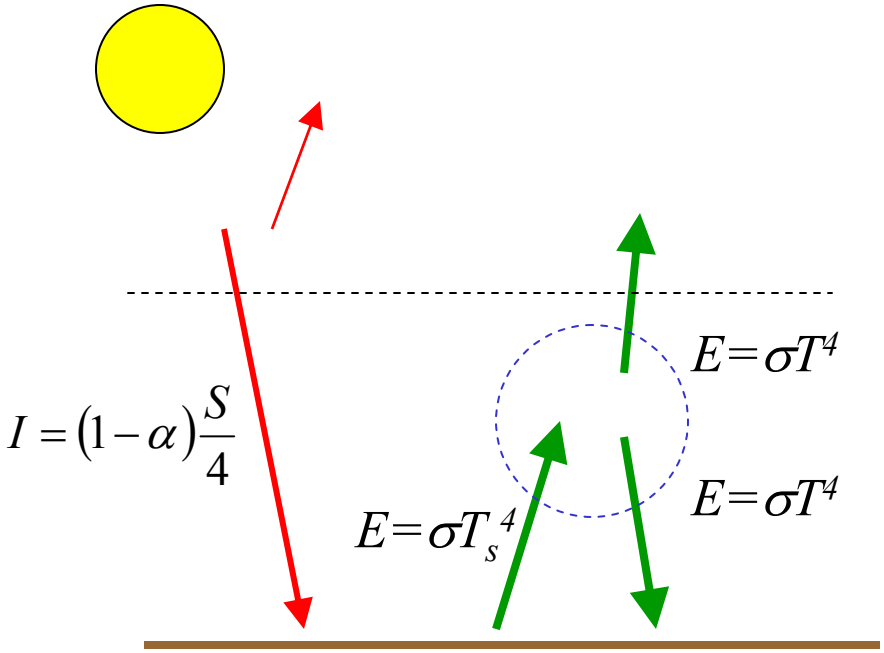
Size of errors

Better selection

Energy balance and greenhouse effect



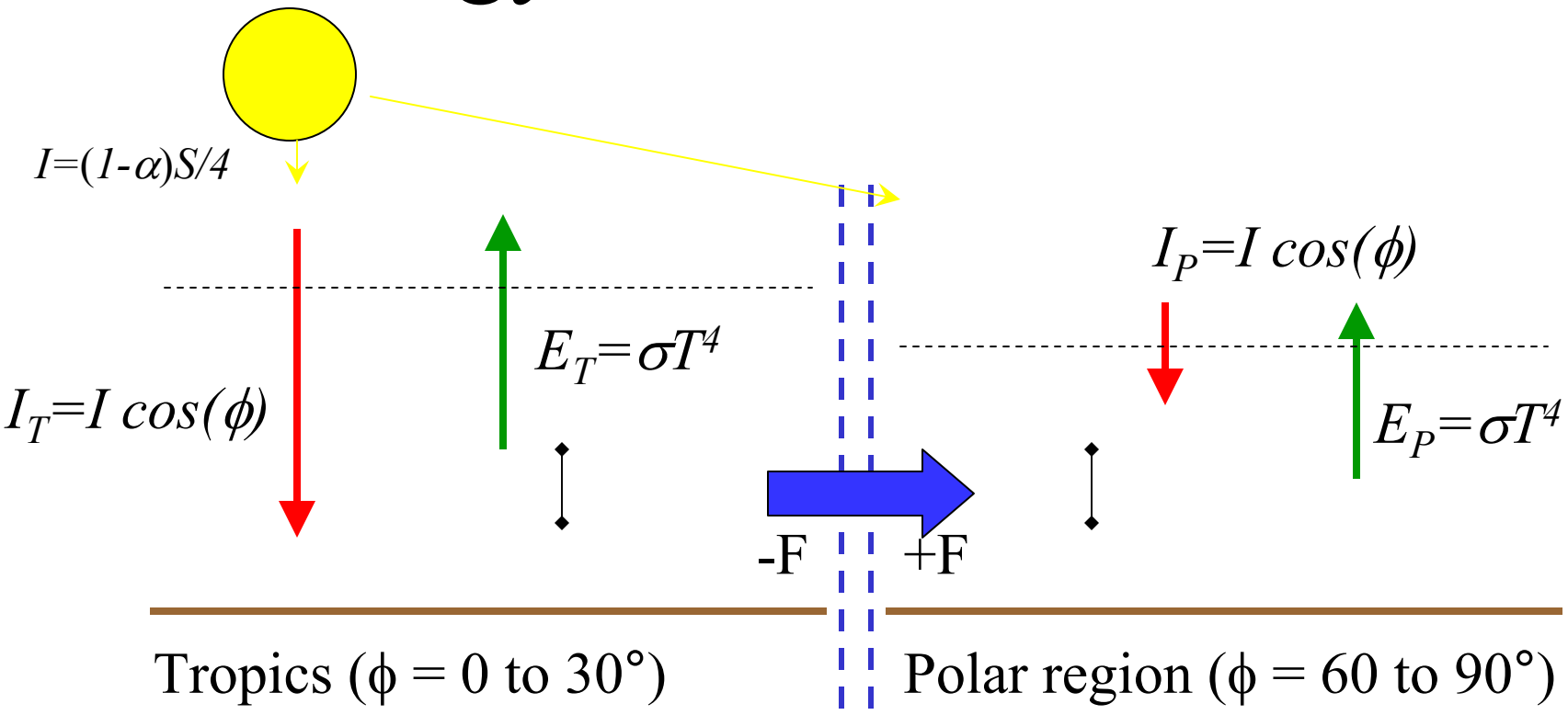
No atmosphere



Greenhouse atmosphere

What are the most important greenhouse gases?
How do we represent them?

Energy balance with latitude



Tropics (ϕ = 0 to 30°)
$I_T > E_T$ i.e., energy surplus

Polar region (ϕ = 60 to 90°)
$I_P < E_P$ i.e., energy deficit

So there MUST be a poleward transport of energy

Energy balance means: $I_T + I_P = E_T + E_P$

So: $I_T - E_T - F = I_P - E_P + F = 0$

Limitations of 0d EBM?

- Lacks non-linear, or other interesting components?
- Very simple response to external forcing…consider some small perturbation.

Thursday's assignment

- Science question: what is the global climate sensitivity*?
- Build a model that includes a greenhouse effect, and estimate the "climate sensitivity"*

* Defined as temperature change when CO_2 is doubled

Things to include in the model…

- An atmosphere
- Some change in longwave due to CO_2
- Water vapor feedback
- …

- Use centered time differences
  (note trick for first time step!)
- Seasons
- Albedo feedback
- Tropical and polar boxes
  (does your model predict polar amplification)?

Volunteer to present scheme/flowchart for a model at the beginning of next class, but discussion on the class wiki starts anytime!