Atmospheric Available Energy and its Trends

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Introduction

The available energy (AE) of a system is a measure of the maximum amount of the total potential energy (TPE) (i.e. the sum of the internal and gravitational potential energies) that can be converted into kinetic energy. Previously, Lorenz (1955) used available potential energy concepts to calculate the energetics of the general circulation associated with baroclinic instability. We use a new and more general formulation of available energy to calculate the global atmospheric available energy. Determining the AE of the atmosphere requires the specification of an isothermal and hydrostatic equilibrium atmosphere. It is the difference between the TPE of the observed atmospheric state and that of the equilibrium atmosphere that gives the available energy. The equilibrium atmosphere is determined by the minimization of a generalized Gibbs function (the "availability function.")

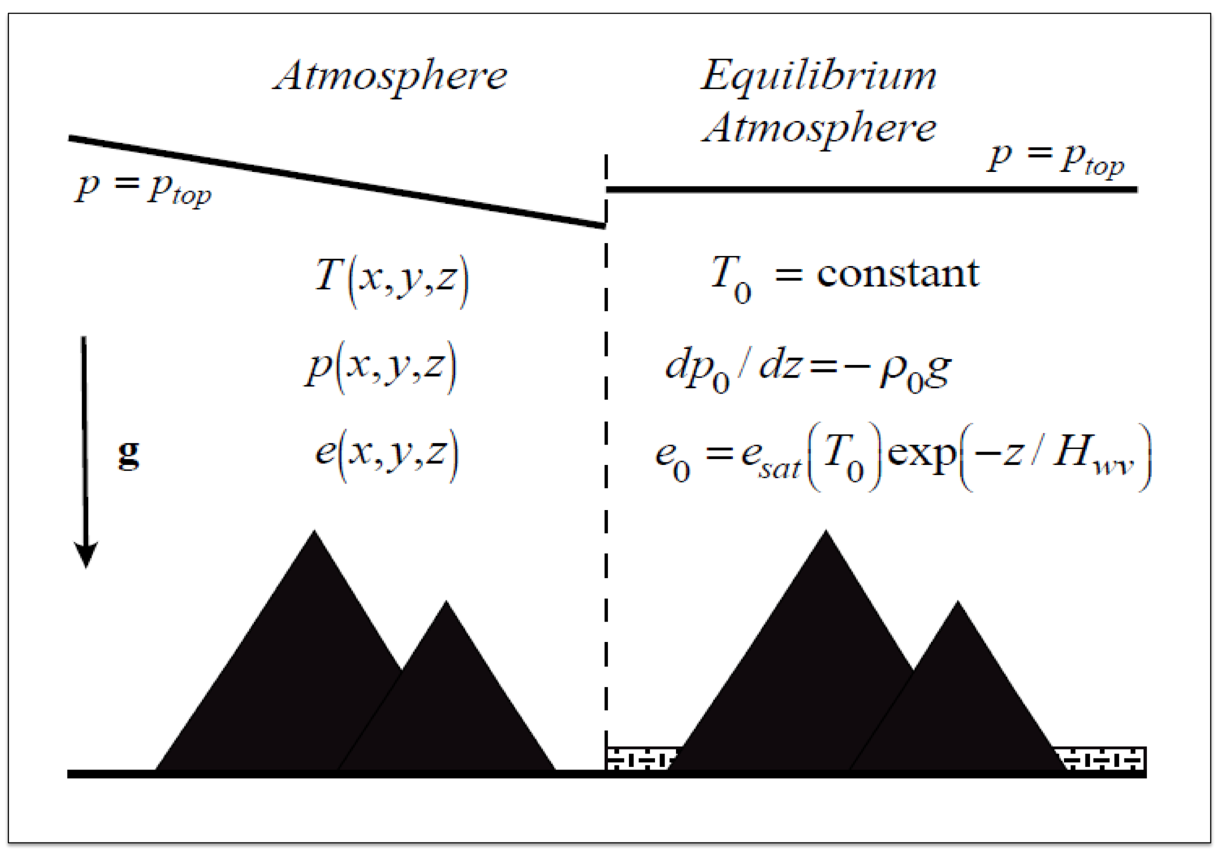


Fig. 1. On the left is a schematic representation of the real atmosphere and on the right is a representation of its isothermal and hydrostatic equilibrium state. Excess water vapour above saturation at the equilibrium temperature is condensed onto the surface.

Data & Theory

Using 34 years from 1979-2012 of monthly mean ECMWF ERA-Interim Reanalysis data to represent the state of the atmosphere, we minimize an availability function to uniquely determine the equilibrium temperature, T_0, and thus the available energy:

$$\delta a_j = \delta h_j - T_0 \delta s_j - \delta p_j/\rho_{j0}$$

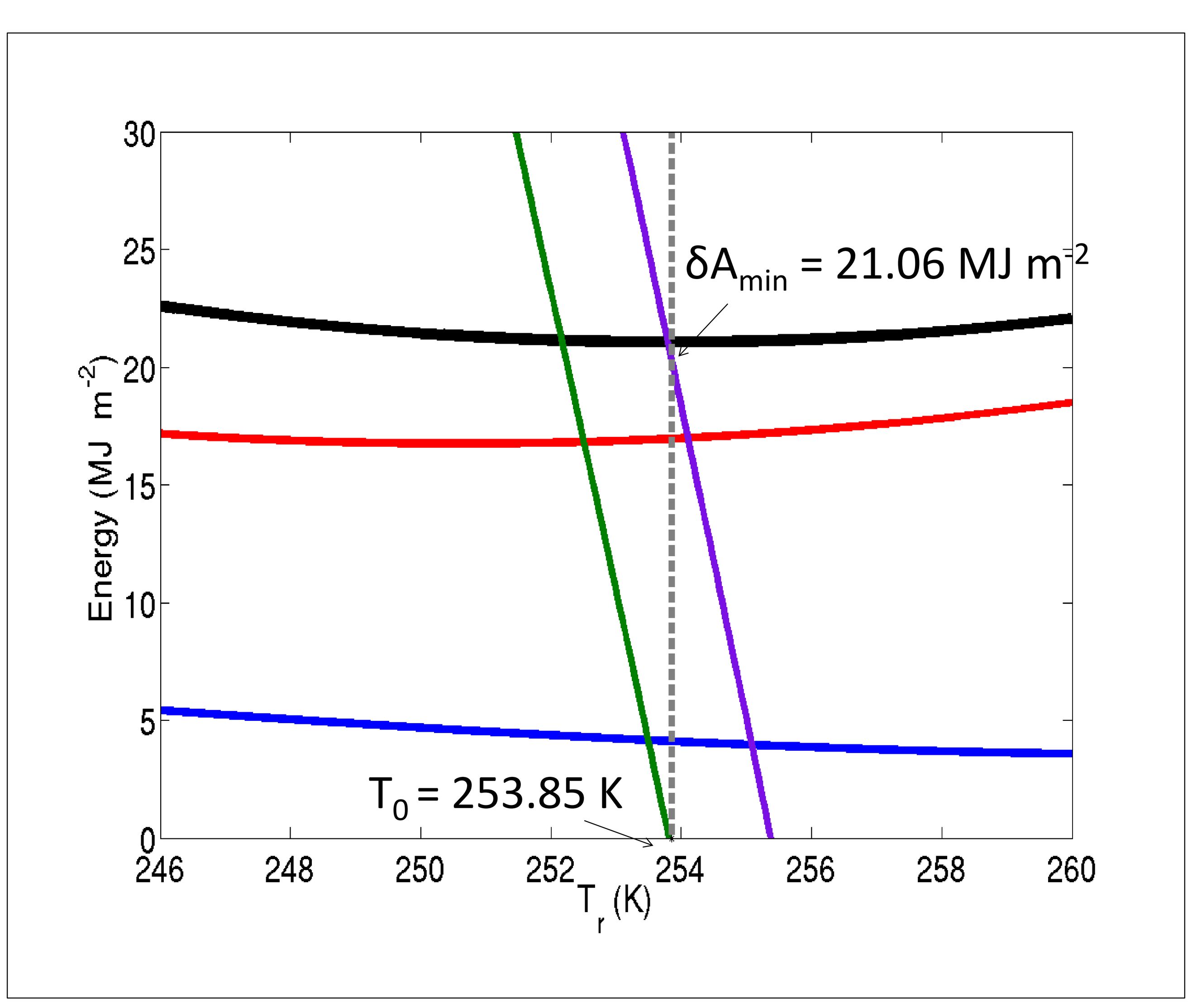
where h_j is the specific enthalpy, T_0 is the equilibrium temperature that minimizes the function, s_j is the specific enthalpy, α_j is the specific volume, and p_j is the partial pressure. The j subscript can be equal to d, v, l or i, which refer to dry air, water vapor, liquid water, and ice, respectively. Here, the δ symbol indicates a finite difference between the atmosphere and its reference state.

Linearization (Bannon, 2012) results in two contributions to the available energy: the available potential (*ape*) and available elastic (*aee*) energies.

$$ape_j \approx \delta\theta_j^2$$
$$aee_j \approx \delta p_j^2$$

The ape is dominated by the dry air contribution, while the aee is dominated by the water vapour contribution. Dry air AE is due mostly to a variance in temperature, while water vapour AE is due mostly to a variance in pressure.

Fig. 2. The availability functions for water vapour (blue) and dry air (red) as well as their sum (black) for a 34-year climatological mean atmosphere. Change in the total potential energy is plotted in purple and change in entropy in green. The global available energy is 21.06 MJ m^{-2} at an equilibrium temperature of 253.85 K. 70 % of the available energy is due to the dry air, with the remaining due to water vapor. Hydrometeors have a negligible contribution.



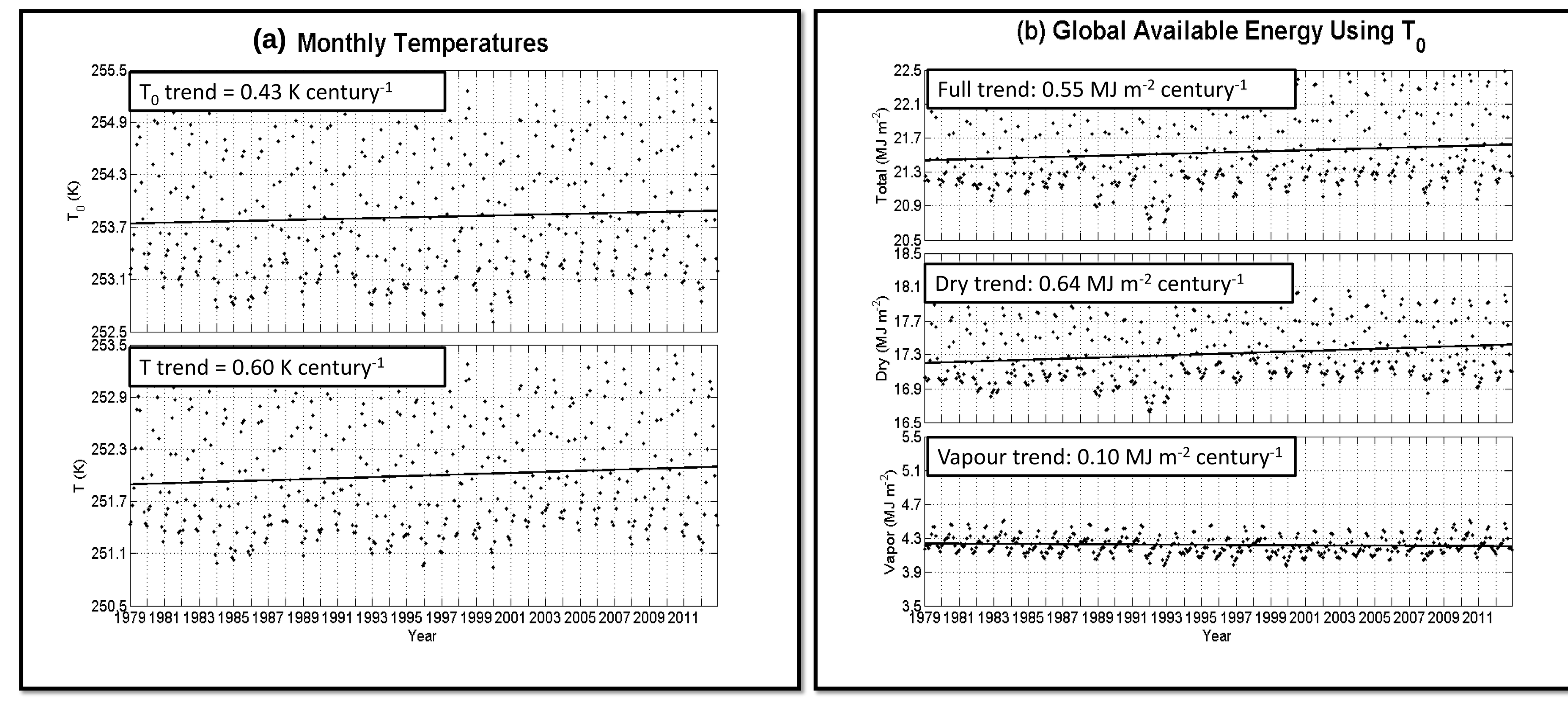
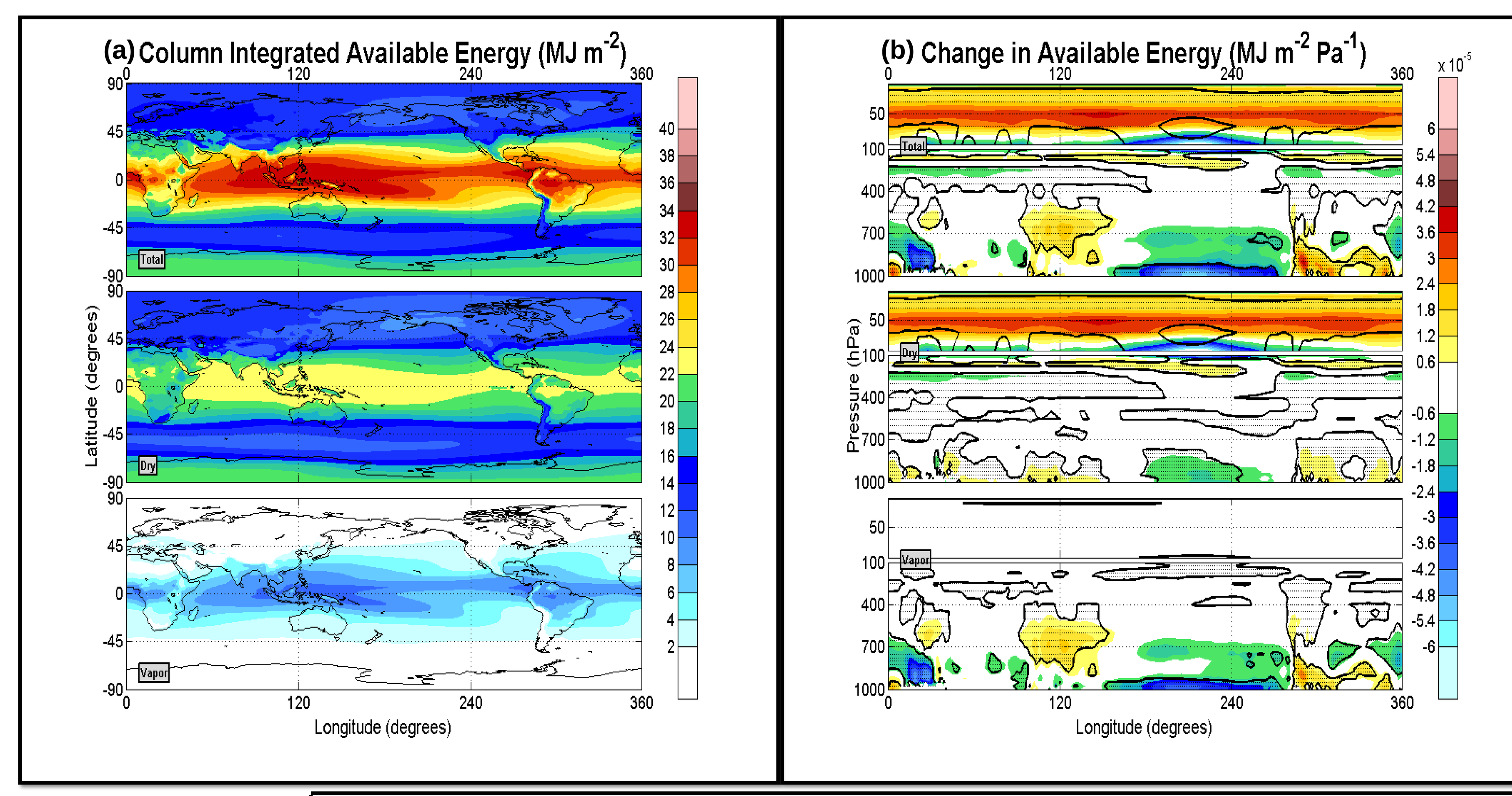


Fig. 3. The monthly values of and the linear trends as given by a least-squares fit in (a) equilibrium and global mass-weighted mean temperatures and (b) the total, dry air and water vapour available energies. Both the equilibrium and mass-weighted mean temperatures are increasing. The total available energy is increasing as a result of increasing dry available energy despite decreasing available energy of water vapour.



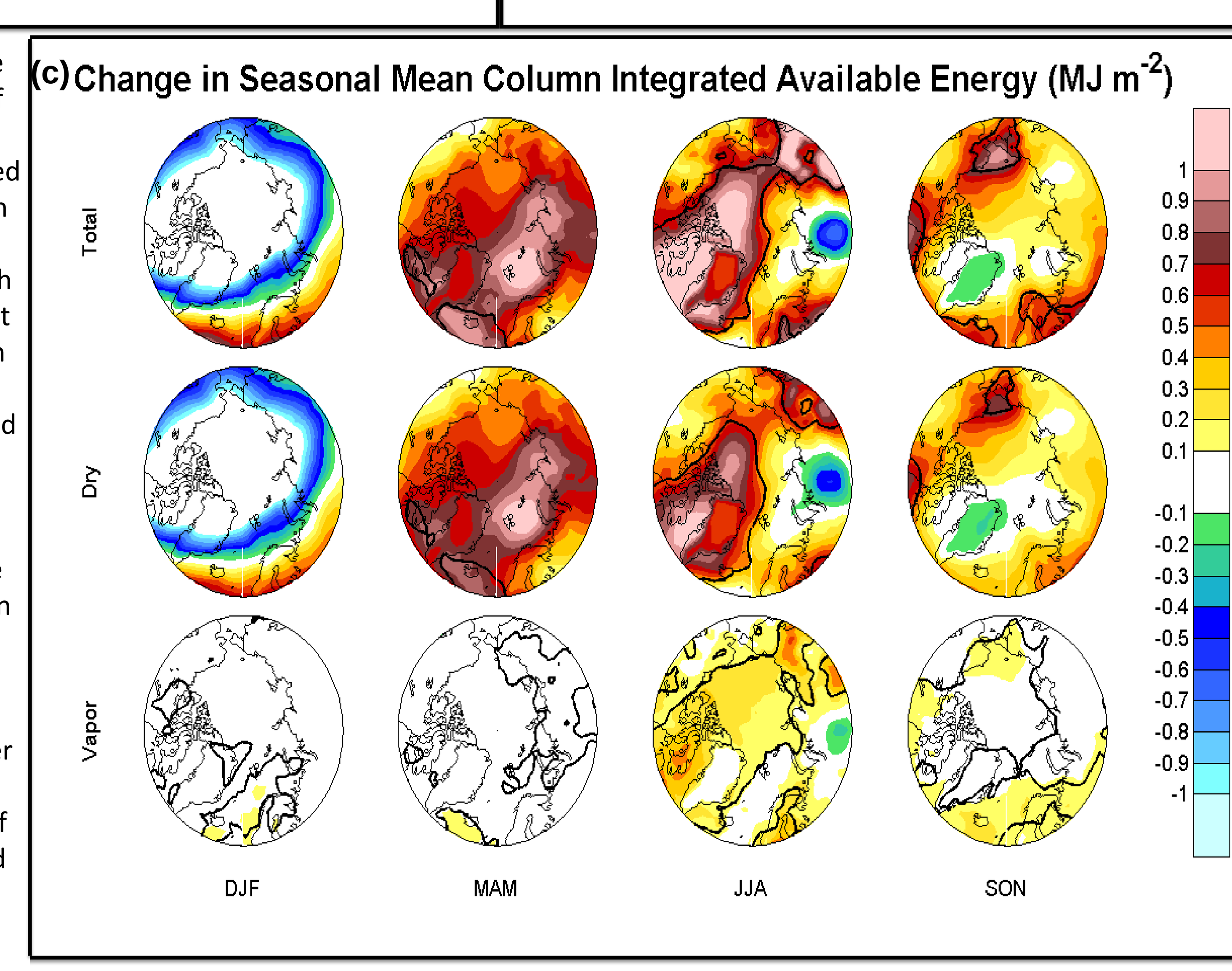


Fig. 4. (a) shows the mean distribution of available energy, which is concentrated near the tropics with a secondary maximum in the high latitudes. (b) is a plot of the trend in mean available energy in the vertical, averaged from 10ºS to 10ºN. The structure suggests a strengthening of the Walker circulation. In (c) is the trend in seasonal mean column integrated available energy over the high northern latitudes. The sign of the trend is reversed and of largest magnitude in DJF as compared to the other seasons.

Conclusions

- Atmospheric available energy is ~5 times larger than APE of Lorenz, with 70% of that coming from the dry air contribution and the rest from water vapour.
- Globally, AE and its equilibrium temperature are increasing in ERA-Interim Reanalysis data. Dry air AE is increasing while water vapour AE is decreasing, though the decrease in water vapour AE is an order of magnitude smaller.
- Locally, AE is increasing in West Pacific and decreasing over Central Pacific.
  → consistent with strengthening of Walker circulation as seen in reanalysis data.
- Seasonally, AE is decreasing over the Arctic in DJF and increasing in all other seasons.
- It isn't clear whether increasing AE indicates more or less "storminess". Conversion terms are needed to complete the theory.

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