Global Energetics in the IGCM Diagnostic Program

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History

The global energetics analysis performed in the diagnostics program (IGFLUX) of the Reading spectral baroclinic model differs from the traditional Available Potential Energy (APE) cycle of Lorenz (1955). Instead, it follows the energy cycle defined by Pearce (1978) with some modifications, summarised below, by Blackburn (1983).

The potential energy component of Pearce's energy cycle was originally called APE following Lorenz, but the source of Pearce's energy component differs fundamentally from that of APE, and Blackburn showed that Pearce's energy cycle is a close approximation to the "Entropic Energy" cycle defined by Dutton (1973). Entropic Energy measures, as a scaled entropy difference, the departure of the global atmosphere from a thermodynamic equilibrium state of maximum entropy, attained at constant energy and mass.

Blackburn showed that Pearce's "APE" is an approximation to the potential energy component of the Entropic Energy, while the kinetic energy (KE) approximates the kinetic component of Entropic Energy. Thus Pearce's "APE" has been renamed the Entropic Potential Energy (EPE), to distinguish it as fundamentally different from Lorenz's APE.

More recently, Marquet (1991) has shown that the Entropic Energy is a particular form of Exergy, which is a measure of maximum work used in engineering thermodynamics.

Interpretation

The Entropic Potential Energy measures the departure of the global atmosphere from isothermal, approximating the scaled entropy difference of the two states by the global temperature variance. The EPE source depends on the rate at which heating increases temperature variance, and is measured by the spatial correlation of heating and temperature. This process increases the departure from isothermal. The sink of EPE is the isentropic conversion to KE, and represents a change in the type of entropic departure from equilibrium, from potential to kinetic.

The main advantage of the budget of EPE over that of APE is that energetic processes affecting the static stability are separated from those affecting lateral temperature variance.

References

Blackburn, M. (1983) "An energetics analysis of the general atmospheric circulation". PhD thesis, University of Reading, UK. 300pp.

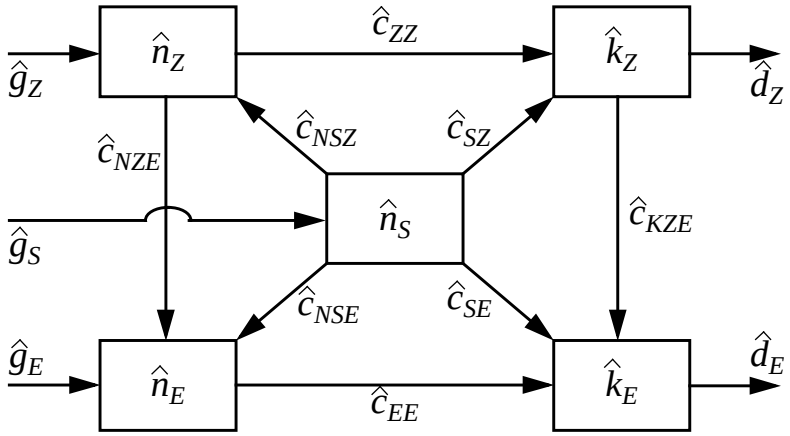
Dutton, J. A. (1973) The global thermodynamics of atmospheric motion. *Tellus*, **25**, 89-110.

Lorenz, E. N. (1955) Available potential energy and the maintenance of the general circulation. *Tellus*, **7**, 157-167.

Marquet, P. (1991) On the concept of exergy and available enthalpy: application to atmospheric energetics. *Q. J. R. Meteorol. Soc*., **117**, 449-475.

Pearce, R. P. (1978) On the concept of available potential energy. *Q. J. R. Meteorol. Soc*., **104**, 737-755.

The Entropic Potential Energy (EPE) and Kinetic Energy (KE) cycle of Pearce & Blackburn



$$\hat{n}_S = \frac{C_p\widetilde{\widetilde{T}'^2}}{2\hat{T}} \qquad \hat{n}_Z = \frac{C_p\widehat{[T]''^2}}{2\hat{T}} \qquad \hat{n}_E = \frac{C_p\widehat{T^{*2}}}{2\hat{T}} \qquad \hat{k}_Z = \frac{1}{2}\widehat{[\underset{\sim}{V}]^2} \qquad \hat{k}_E = \frac{1}{2}\widehat{[\underset{\sim}{V}^{*2}]}$$

$$\hat{g}_S = \frac{\widetilde{\widetilde{q}'\widetilde{T}'}}{\hat{T}} \qquad \hat{g}_Z = \frac{\widehat{[q]''[T]''}}{\hat{T}} \qquad \hat{g}_E = \frac{\widehat{q^*T^*}}{\hat{T}}$$

$$\hat{c}_{NSZ} = -\overline{\left(\frac{R\widehat{[\omega][T]''}}{p}\right)'\left(\frac{p}{\kappa\hat{T}}\frac{\partial\widetilde{\widetilde{T}}'}{\partial p}\right)'} \qquad \hat{c}_{NSE} = -\overline{\left(\frac{R\widehat{\omega^*T^*}}{p}\right)'\left(\frac{p}{\kappa\hat{T}}\frac{\partial\widetilde{\widetilde{T}}'}{\partial p}\right)'}$$

$$\hat{c}_{NZE} = -\frac{C_p}{\hat{T}}\left(\widehat{[v^*T^*]\frac{1}{a}\frac{\partial[T]''}{\partial\phi}} + \widehat{[\omega^*T^*]''\frac{\partial[T]''}{\partial p}}\right)$$

$$\hat{c}_{SZ} = -\overline{\left(\frac{R\widehat{[\omega][T]''}}{p}\right)}\,\overline{\left(\frac{p}{\kappa\hat{T}}\frac{\partial\widetilde{\widetilde{T}}'}{\partial p}\right)} \qquad \hat{c}_{SE} = -\overline{\left(\frac{R\widehat{\omega^*T^*}}{p}\right)}\,\overline{\left(\frac{p}{\kappa\hat{T}}\frac{\partial\widetilde{\widetilde{T}}'}{\partial p}\right)}$$

$$\hat{c}_{ZZ} = -\overline{\left(\frac{R\widehat{[\omega][T]''}}{p}\right)}\left(1 - \overline{\frac{p}{\kappa\hat{T}}\frac{\partial\widetilde{\widetilde{T}}'}{\partial p}}\right) \qquad \hat{c}_{EE} = -\overline{\left(\frac{R\widehat{\omega^*T^*}}{p}\right)}\left(1 - \overline{\frac{p}{\kappa\hat{T}}\frac{\partial\widetilde{\widetilde{T}}'}{\partial p}}\right)$$

$$\hat{c}_{KZE} = -\cos\phi\overline{\left([u^*v^*]\frac{1}{a}\frac{\partial}{\partial\phi} + [u^*\omega^*]\frac{\partial}{\partial p}\right)\left(\frac{[u]}{\cos\phi}\right)}$$
$$-\cos\phi\overline{\left([v^{*2}]\frac{1}{a}\frac{\partial}{\partial\phi} - [u^{*2} + v^{*2}]\frac{\tan\phi}{a} + [v^*\omega^*]\frac{\partial}{\partial p}\right)\left(\frac{[v]}{\cos\phi}\right)}$$

$$\hat{d}_Z = -\widehat{[\underset{\sim}{V}]\cdot[\underset{\sim}{F}]} \qquad \hat{d}_E = -\widehat{[\underset{\sim}{V}^*\cdot\underset{\sim}{F}^*]}$$

Averaging Operators

The spatial averaging operators used here closely follow the nomenclature of Pearce (1978), the single exception being the use here of a single rather than double star for zonally asymmetric eddy departures.

There is one averaging/departure operator-pair for each of the spatial dimensions, plus one operator for the combination of all three dimensions.

Averaging type	Average operator	Departure operator
Zonal	$[\,a\,]$	a^*
Meridional (area)	$\widetilde{a}$	a''
Vertical (mass)	$\overline{a}$	a'
Global (mass)	$\widehat{a}$	(not used)

Notes:

$\widehat{a} = \overline{\widetilde{a}}$, shorthand for $\overline{\widetilde{[\,a\,]}}$

$\widetilde{a}'$ = departure of isobaric level average from 3D global average.

$[a]''$ = departure of zonal average from isobaric level average.

Correlations / variances:

$[\,a^*b^*]$ zonal average of departures of local values from zonal averages.

$\widetilde{[\,a]''[b]''}$ meridional average of departures of zonal averages from meridional averages.

$\overline{\widetilde{a}'\,\widetilde{b}'}$ vertical average of departures of level averages from global 3D averages.