The Periodic Behavior of Tropical Jet Available Potential Energy

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1. Background and Data

Specific Available Potential Energy (APE), with respect to a fully mixed atmosphere, is defined as:

$$APE = \frac{\rho - \rho_{mixed\,atmos}}{\rho} gz \quad (J/kg)$$

Thus, the difference of APE across the subtropical jet, with respect to a standard atmospheric sounding, is the Jet Available Potential Energy (JAPE), defined as:

$$JAPE = \frac{\rho - \rho_{std.\,atmos}}{\rho} gz \quad (J/kg)$$

This analysis utilizes ECMWF Re-Analysis – Interim (ERA-I) four-times-daily data from 1979 January 1 through 2014 December 31, with layer-averaged JAPE values calculated via:

$$\{JAPE\} = \iint_{x,y} \int_z JAPE\, \rho\, dV \quad (J)$$

As this analysis will use isentropic layers,

$$\int_z = \int_{z_{\theta_1}}^{z_{\theta_2}} dz \quad (J)$$

where $dz = z_{\theta 2} - z_{\theta 1}$

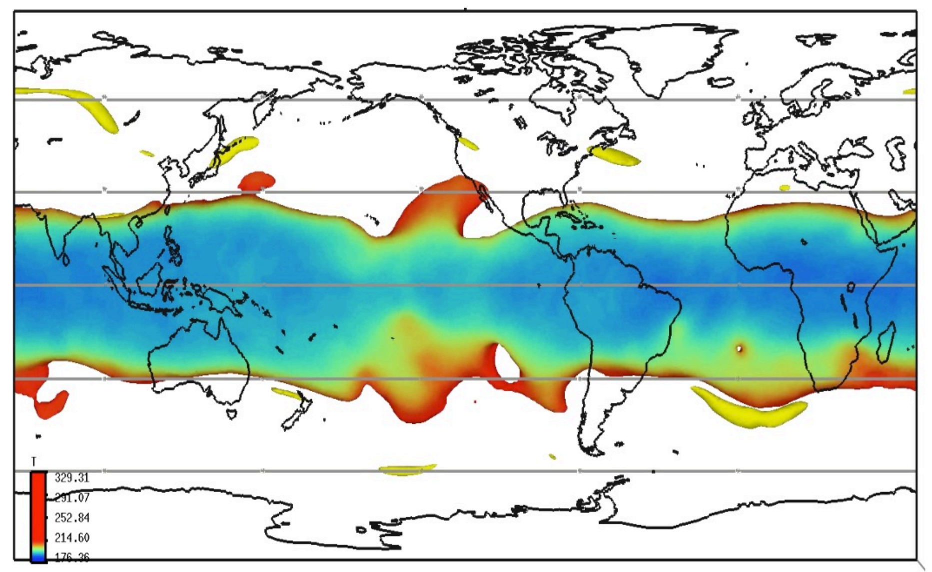

Figure 1: JAPE Bubble (multicolored surface) and subtropical jets (yellow surfaces) as seen 1200 UTC 18 March 2013

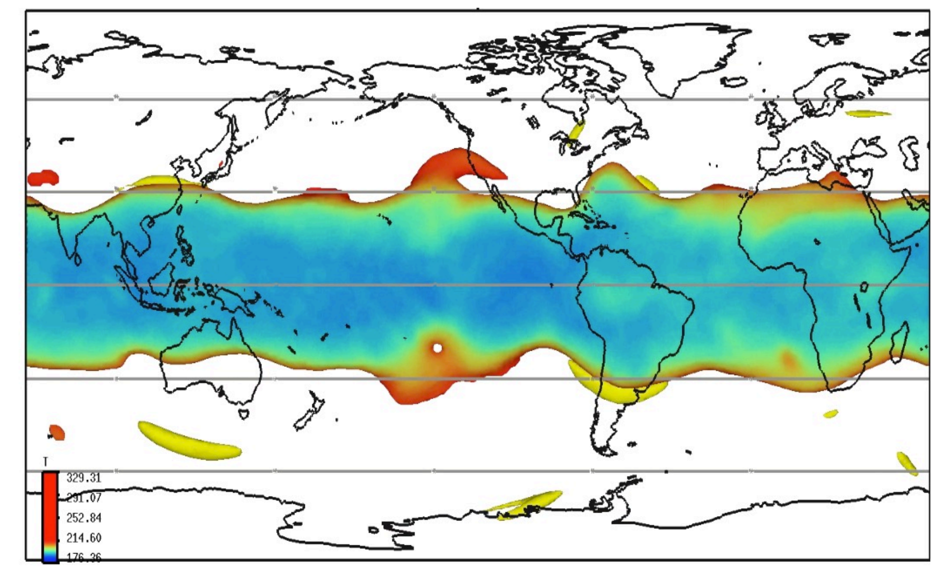

Figure 2: JAPE Bubble (multicolored surface) and subtropical jets (yellow surfaces) as seen 0000 UTC 27 October 2012, at the peak of Hurricane Sandy.

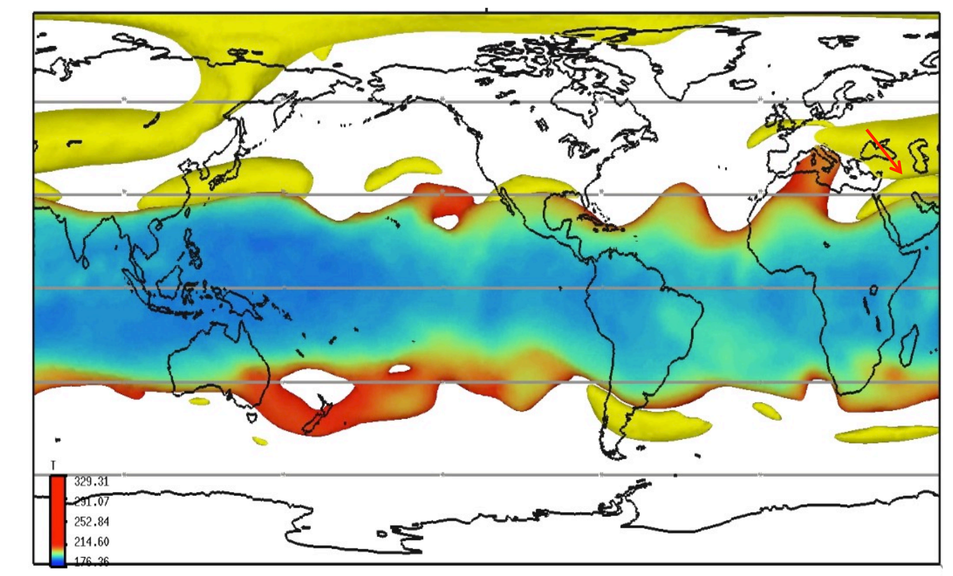

Figure 3: JAPE Bubble (multicolored surface) and polar and subtropical jets (yellow surfaces) as seen 1200 UTC 23 December 2012. Energy release denoted with red arrow.

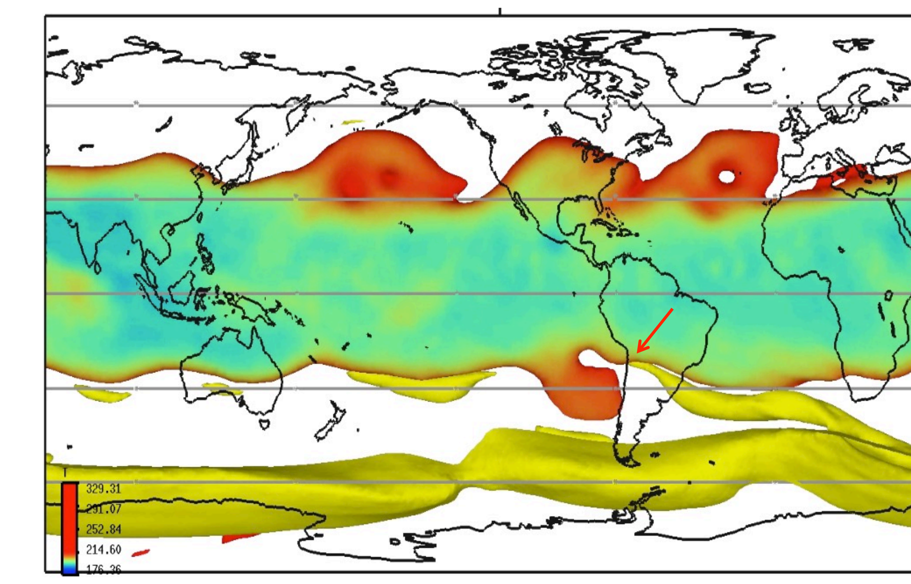

Figure 4: JAPE Bubble (multicolored surface) and polar and subtropical jets (yellow surfaces) as seen 1200 UTC 26 August 2013. Energy release denoted with red arrow.

Integrated JAPE is the total potential energy stored in the tropical JAPE bubble, which must eventually be fluxed to the extratropics. Over time, mean JAPE builds up and bleeds off to the extratropics in response to tropical plumes transporting JAPE out of the bubble. This is seen to occur frequently over time, leading to an investigation of the periodicity of the rises and falls of energy within the bubble.

The JAPE bubble is bounded by the subtropical jet and the elevated tropical tropopause. It is restricted by both inertial and radiative forces, as angular momentum prevents lateral movement while the lack of net radiation inhibits vertical motion. The integrated outflow mass from tropical convection and storms causes APE to accumulate in the Upper Troposphere - Lower Stratosphere (UTLS).

APE must therefore be released via extratropical interactions with the lower troposphere or the surface. A mixture of APE from tropical convection and angular momentum transport are found to be responsible for the creation of subtropical jets. The subtropical jet forms along the poleward boundary of a UTLS JAPE plume. The JAPE plume carries both potential and kinetic energy from the jet poleward, transporting APE out of the tropics and into the extratropical Rossby Wave Train (RWT). Regional-scale JAPE plume surges like this overcome restrictions to mean global scale meridional overturning caused by angular momentum, thus allowing APE to flow towards the poles where it can radiate out of the atmosphere and angular momentum can be dissipated into the ground via surface friction.

2. Single Year Analysis

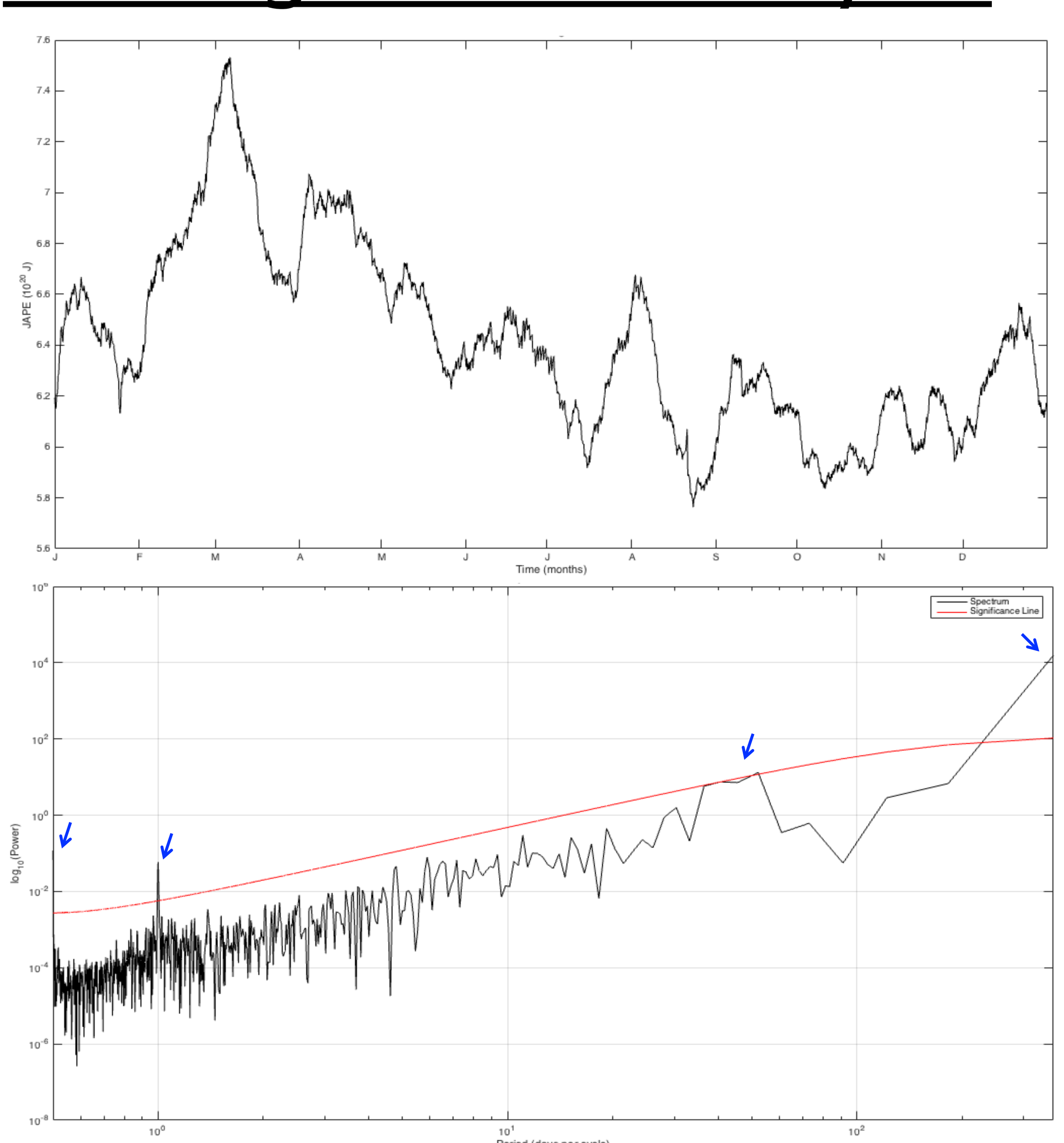

Figure 5: Upper - Time series of 1 January 2005 through 31 December 2005 layer-averaged JAPE over the tropics (defined as 30°N-30°S) at the 370-380 K isentropic layer. Lower – Spectral analysis of the same single-year time series. Blue arrows denote significant peaks of interest.

The time series shows cyclic behavior, revealing at first glance daily and 20-60-day cycles.

Spectral Analysis performed using an AR(2) process and 95% confidence levels reveal prevalent periods lasting 0.5, 1, 40-50, and 365 days.

3. 36-Year Analysis

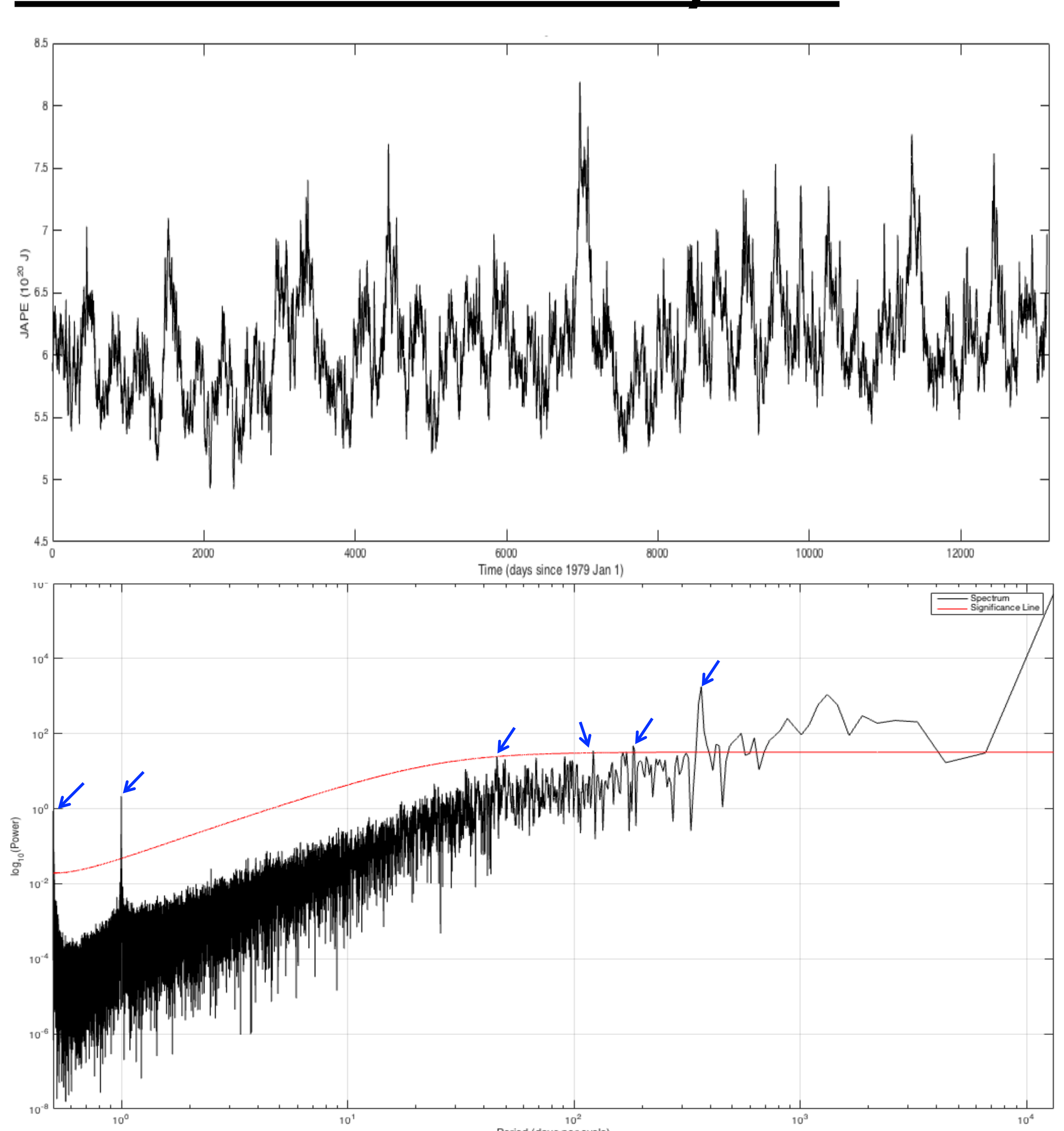

Figure 6: Upper - Time series of 1 January 1979 through 31 December 2014 layer-averaged JAPE over the tropics (defined as 30°N-30°S) at the 370-380 K isentropic layer. Lower – Spectral analysis of the same multi-year time series. Blue arrows denote significant peaks of interest.

Spectral Analysis using an AR(2) process and 95% confidence levels reveal prevalent periods lasting 0.5, 1, 45, 122, 182, and 365 days.

Longer, "significant" periods are seen, but currently deemed "uninteresting" due to lack of data at longer range.

4. Annual Cycle

One cycle of particular interest, the annual cycle, is very well-defined in both the single- and multi-year analyses. By averaging four-times-daily data into one daily point, and then averaging daily data across 36 years, a general trend is seen. This is what is done in Fig. 7. It becomes evident that the highest JAPE values are found late January and early February, while the lowest values are found late September through October.

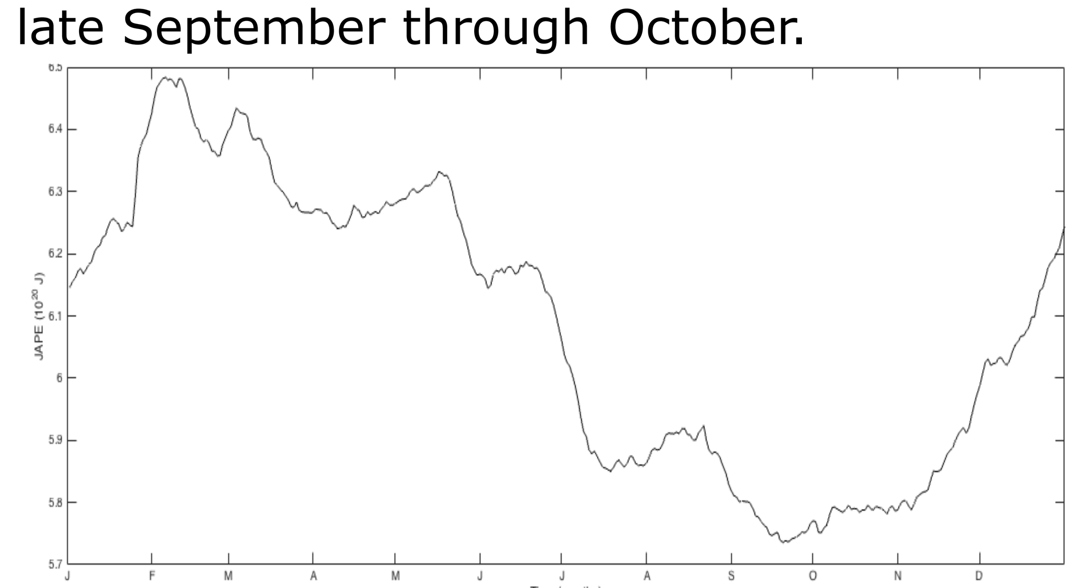

Figure 7: Daily-averaged, layer-averaged JAPE over the tropics (defined as 30°N-30°S) at the 370-380 K isentropic layer.

However, the question can be raised, if the Northern and Southern Hemispheres receive approximately equal radiation annually, why is an annual cycle present? One possible answer to this is that the Southern Hemisphere is more "efficient" at releasing energy throughout the year, while the Northern Hemisphere better releases energy during the boreal late summer and early fall.

5. 45-Day Cycle

Another cycle of interest, the 45-day cycle aligns with the 30-60 day cycle seen of the Madden Julian Oscillation (MJO), suggesting a possible connection. High levels of tropical convection associated with the oscillation could serve as a source of a large amount of energy to the tropical JAPE bubble. This raises the question, why would a localized phenomenon affect a global energy reservoir? One hypothesis is that high levels of convection constantly fuel the JAPE bubble, while eruptions from the bubble can occur wherever there is a connection to the subtropics via a subtropical jet.

6. Conclusions

- Interesting prevailing peaks in frequency are seen at periods equal to 0.5, 1, 45, and 365 days per cycle.
- A 45-day cycle could indicate increased influence by the MJO, emphasizing that local events could have globally-experienced effects.
- The annual cycle suggests unbalanced efficiency in energy release between the Northern and Southern Hemispheres.
- On average, the highest JAPE values occur in January - March, while the lowest JAPE values occur in September – November.

7. References

Krishnamurti, T. N., 1961: On the role of the subtropical jet stream of winter in the atmospheric general circulation. *J. Meteor.*, **18**, 657-670.

Lorenz, E. N., 1955: Available Potential Energy and the Maintenance of the General Circulation. *Tellus*, **2**, 157-167.