Using Enstrophy Advection as a Diagnostic to Identify Blocking Regime Transition

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Blocking from Above

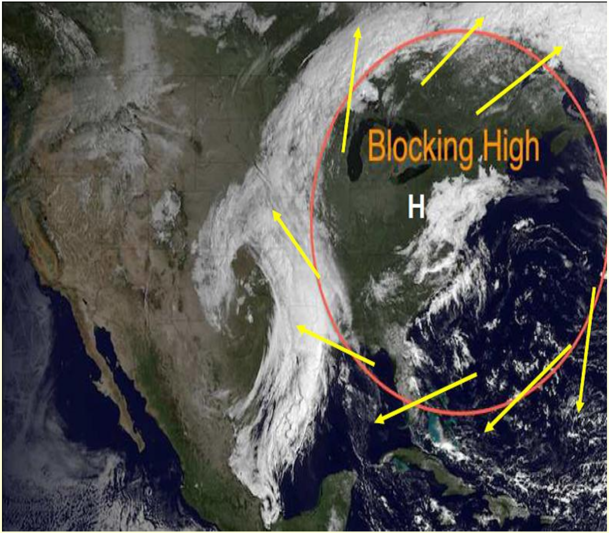


Figure: March 21st 2012, GOES-East

The Predictability Problem

- Notwithstanding the nearly stationary nature of blocking events, the flow is unstable during block onset and decay.
- Because of this instability, forecasts for regions in and near the block are often less accurate, (Tibaldi and Molteni 1990).
- Errors in model output are largest at onset and decay, smallest during a mature block, (Frederiksen et al., 2004)
- So, lets exploit the instability.

Purpose

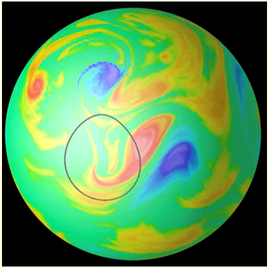
The purpose of this research is to:

- Develop a technique that extends the results of Lupo et al. 2007, etc., and demonstrate that this new technique (DIRE) can be used to detect blocking onset and decay;
- Demonstrate the ways in which contours of enstrophy advection may be useful in detecting blocking events.

Blocking Diagnostic-Introductory Items

Definition

Relative vorticity = $\frac{circulation}{area}$. *Denoted by* ζ.



Definition

For our purposes enstrophy is vorticity squared, ζ^2.

Blocking Diagnostic-Previous Work

- Local Lyapunov exponents λ_i are the finite time version of Lyapunov exponents: essentially, they quantify the rate of separation of nearby trajectories for small times.
- For an incompressible, frictionless, barotropic flow, it was shown that

$$\sum_{\lambda_i > 0} \lambda_i \approx \int \zeta^2$$

over a fixed, finite and bounded domain, where ζ is vorticity (see Dymnikov, 1992).

Blocking Diagnostic-Previous Work, Continued

- Previous work has shown that $\sum_{\lambda_i > 0} \lambda_i \approx \int \zeta^2$, the integrated enstrophy (IRE), is useful in identifying blocking onset and decay (see Lupo et al. 2007, 2012, etc.).
- Low values of IRE imply a more predictable or stable state, while high values of IRE imply a more unstable state in the flow.
- The same work has shown that the IRE reaches a relative maximum value at block onset and decay, while it decreases to a relative minimum during the block as the flow stabilizes.

New Diagnostic: Integral of Enstrophy Advection (DIRE)

- Feynman: “Then I come along and try differentiating under the integral sign, and often it worked.”
- Combining the previous ideas, a simple calculation yields:

$$\frac{\partial\left(\sum_{\lambda_i>0}\lambda_i\right)}{\partial t} \approx \frac{\partial}{\partial t}\int \zeta^2 = -\int \mathbf{V}\cdot\nabla\zeta^2.$$

- The interpretation of stability reduces to determining the sign of the integral of enstrophy advection (DIRE).

New Diagnostic-Interpretation

- If $-\int \mathbf{V} \cdot \nabla\zeta^2 < 0$, the flow instability is decreasing.
- If $-\int \mathbf{V} \cdot \nabla\zeta^2 > 0$, the flow is becoming more unstable.
- Regions in which $-\int \mathbf{V} \cdot \nabla\zeta^2$ changes from positive to negative are where a local maximum in instability is expected.
- Specifically, regions of positive DIRE and local maxima should correlate to block onset and decay.

Data

- Calculations of IRE and DIRE were performed using spherical coordinates.
- The data set used for the calculations was the NCEP-NCAR gridded reanalysis data.
- The 0000 UTC NCEP-NCAR reanalyses of gridded ($2.5^\circ \times 2.5^\circ$) u and v components of the wind at 500 mb were used in all calculations of IRE and DIRE.

Four Northern Hemisphere Blocking Events

Date	BI	LON
January 6-12, 2012	3.69	60 E
January 9-16, 2012	3.55	20 W
January 12-27, 2012	5.01	130 W
January 17-29, 2012	3.61	60 E

Table: January 2012 Northern Hemisphere blocking events. Block intensity and longitude at block onset.

IRE: Block onset

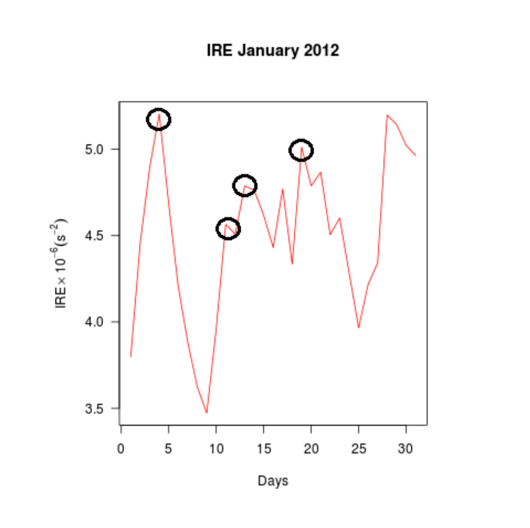


Figure: Time series of NH area averaged IRE for the month of January 2012. Block onset for the events in the table can be seen as local maxima.

DIRE: Block onset

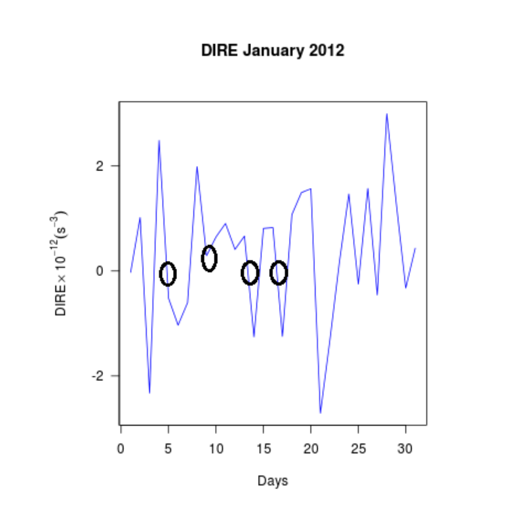


Figure: Time series of NH area averaged DIRE for the month of January 2012. Block onset for the events in the table can be seen as positive values crossing the time axis to negative values.

IRE: Block decay

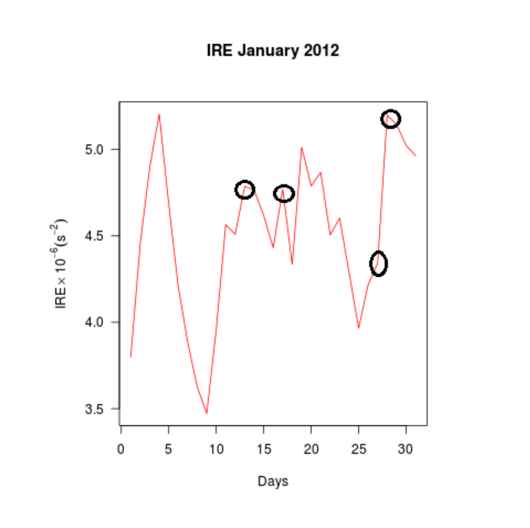


Figure: Same time series of NH area averaged IRE for the month of January 2012 with block decay for the events in the table highlighted.

DIRE: Block decay

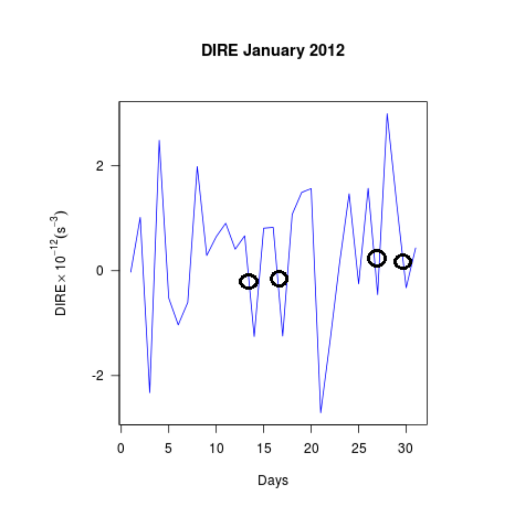


Figure: Same time series of NH area averaged DIRE for the month of January 2012 with block decay for the events in the table highlighted.

Conclusions: DIRE and IRE

- For the four events studied, DIRE was comparable to IRE in detecting block onset and decay.
- Advantage: Not necessary to search for relative extrema, just the sign of DIRE.
- Block onset was easier to locate with IRE than with DIRE.
- Block decay was easier to locate with DIRE than with IRE.
- When used together, however, IRE and DIRE provide a more comprehensive view of the stability of a hemisphere or region.

Another Diagnostic: Enstrophy Advection

- The quantity $-\mathbf{V} \cdot \nabla \zeta^2$ determines the sign of $-\int \mathbf{V} \cdot \nabla \zeta^2$.
- Thus we may also consider the enstrophy advection, $-\mathbf{V} \cdot \nabla \zeta^2$, as an indicator of increasing or decreasing instability.
- The interpretation is analogous to that of the integral of enstrophy advection.

Interpretation

- DIRE is a single number that represents the average stability of an entire hemisphere.
- A time series must be used to determine trends in instability.
- But, it's not evident what is occurring in a smaller, more local region of a blocking event.
- Thus, contours of enstrophy advection can be plotted to visualize the effect enstrophy may have on blocking events.
- 500 mb heights are also plotted for easier visualization of blocking.

Data Again

- The same NCEP-NCAR reanalysis data set was used.
- Also data from the Global Forecast System (GFS, 0.5° resolution) was used to compare the reanalysis data with model predictions.

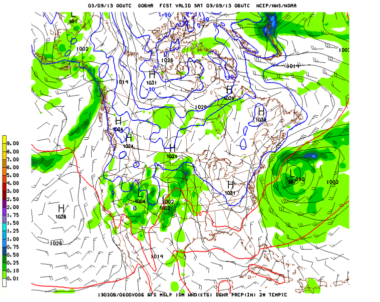


Figure: Example GFS model output

Contours: GFS vs Reanalysis

- Contours of enstrophy advection from a Southern Hemisphere blocking event from February 14-20, 2013, centered at 130 E at onset, are plotted.
- Solid contours are positive enstrophy advection, dashed contours are negative enstrophy advection.
- All contours represent instability, however.
- The idea is to compare contours of enstrophy advection obtained from reanalysis data with contours of enstrophy advection obtained from GFS model data.

GFS vs reanalysis

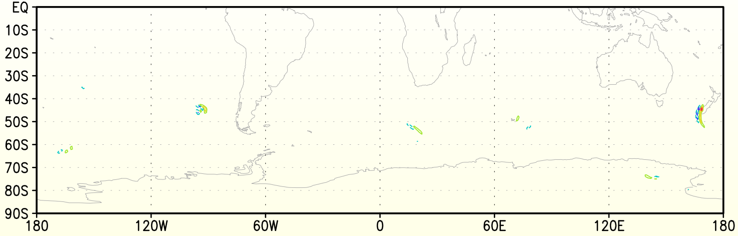


Figure: Feb. 11th hemispheric GFS contours of enstrophy advection. Not much enstrophy advection generally.

GFS vs reanalysis

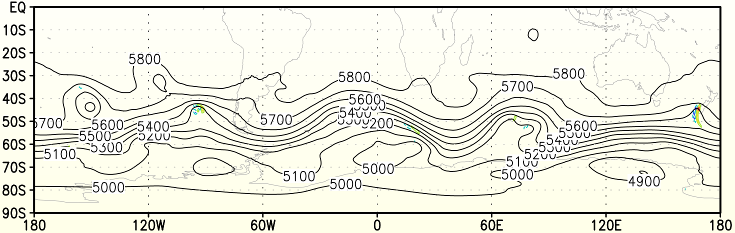


Figure: Feb. 11th GFS hemispheric contours of enstrophy advection with height contours. Flow before block onset is shown.

GFS vs reanalysis

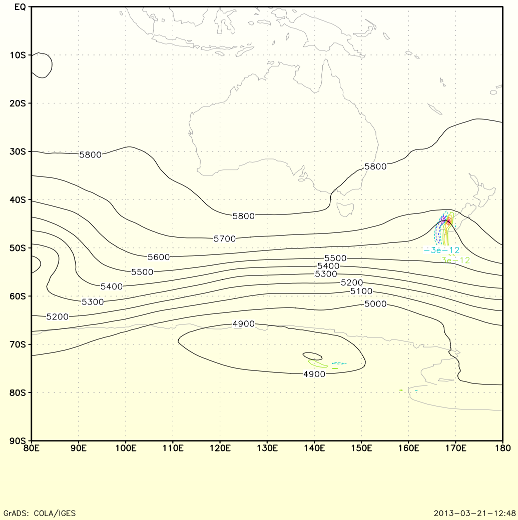


Figure: Feb. 11th GFS contours of enstrophy advection. Block onset instability is shown.

GFS vs reanalysis

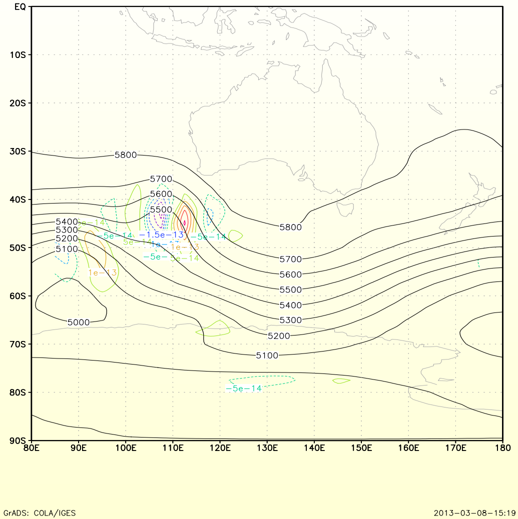


Figure: Feb. 14th reanalysis contours of enstrophy advection. Block onset instability can be seen.

GFS vs reanalysis

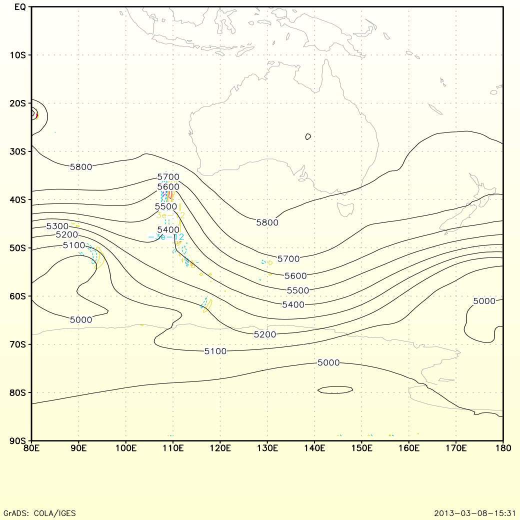


Figure: Feb. 14th GFS contours of enstrophy advection. Block onset instability is shown.

GFS vs reanalysis

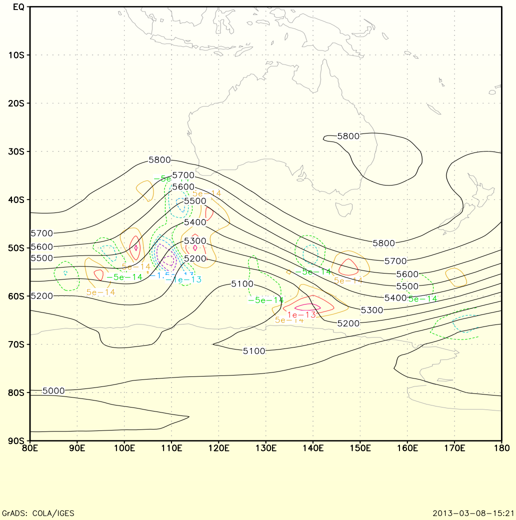


Figure: Feb. 17th reanalysis contours of enstrophy advection. Block has matured.

GFS vs reanalysis

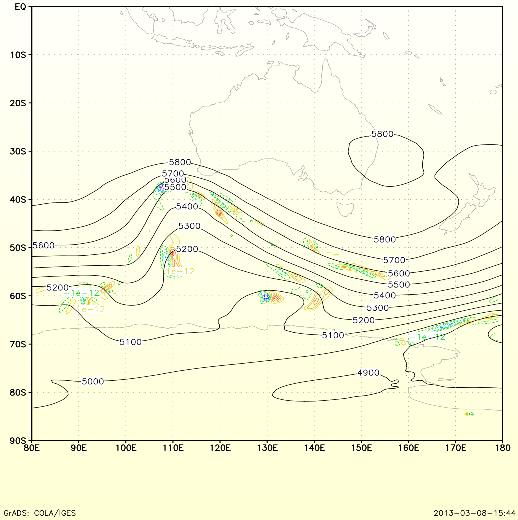


Figure: Feb. 17th GFS contours of enstrophy advection. Block has matured.

GFS vs reanalysis

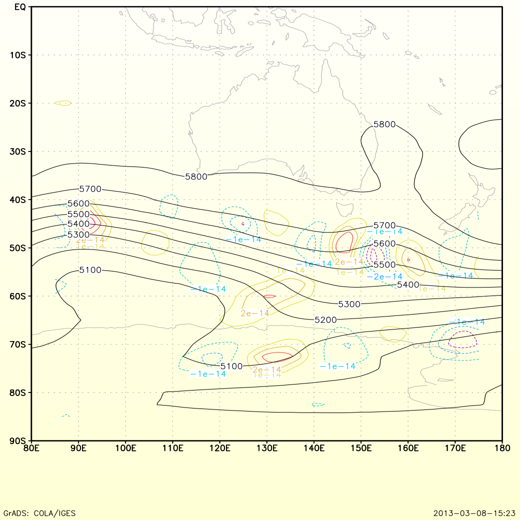


Figure: Feb. 20th reanalysis contours of enstrophy advection. Block decay instability is shown.

GFS vs reanalysis

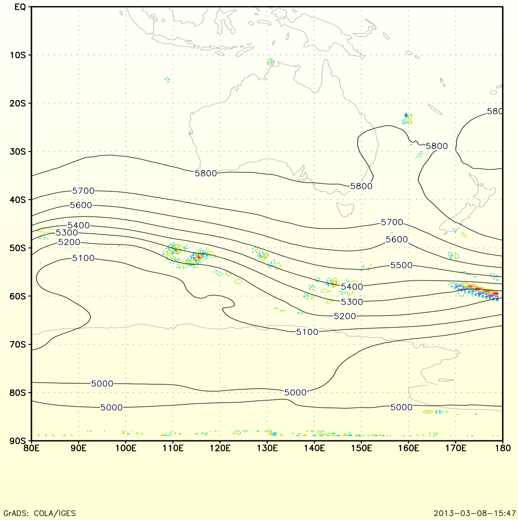
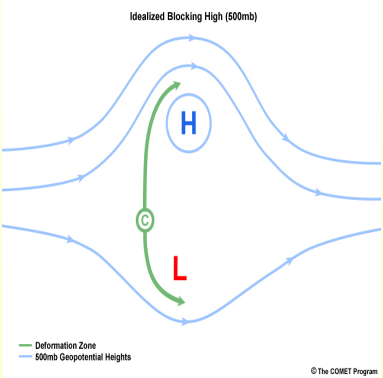


Figure: Feb. 20th GFS contours of enstrophy advection. Block decay instability is shown.

Advection Equation

- To explain the physics behind the enstrophy advection, the Okubo-Weiss criterion is considered: $\frac{1}{2}\left(E^2 - \zeta^2\right)$, $E =$ total deformation.
- This criterion can be used to locate strain dominated regions or vorticity dominated regions in a flow.



Advection Equation Continued

- This expression can be combined with the 2D pressure Poisson equation: $-\frac{1}{\rho}\nabla^2 p = \frac{1}{2}\left(E^2 - \zeta^2\right)$.
- It can then be shown that

$$-\mathbf{V} \cdot \nabla\zeta^2 = 2f\mathbf{V}_{ag} \cdot \nabla\zeta_{ag} + \frac{\partial E^2}{\partial t}.$$

Description of Terms: $-\mathbf{V} \cdot \nabla \zeta^2 = 2f\mathbf{V}_{ag} \cdot \nabla \zeta_{ag} + \frac{\partial E^2}{\partial t}$

- There are three terms to describe.
- Term (1): $-\mathbf{V} \cdot \nabla \zeta^2$.
- This term represents the transport of enstrophy (vorticity squared) by the wind at 500 mb (in our case).
- Term (2) $2f\mathbf{V}_{ag} \cdot \nabla \zeta_{ag}$ represents the transport of the ageostrophic part of vorticity by the ageostrophic wind.
- Term (3), $\frac{\partial E^2}{\partial t}$, represents the time evolution of deformation.

Conclusion

- The DIRE and enstrophy advection along with the previously obtained IRE may be useful in detecting blocking onset and decay.
- An interpretation of the physical processes was made and they were shown to be related to total deformation and ageostrophic advections.
- Questions?
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