An improved algorithm for detecting blocking events

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Introduction

• Circulation anomalies known as “blocks” catch our attention because they occasionally spawn exceptional weather.

• A block often takes the shape of a “modon”: a meridionally aligned cyclone-anticyclone pair.

Modons are exact solutions of the quasi-geostrophic shallow-water equations on a beta plane and appear to have attractor-like properties.

Detection of blocks in model output

• **Tibaldi-Molteni** index: triggered by reversal of meridional 500mb height gradient (indicating presence of anticyclone poleward of cyclone).

• **Pelly-Hoskins** index: triggered by reversal of pot.temperature gradient on tropopause–level pot.vorticity surface (indicating breaking Rossby wave).

• For simplicity, focus here on Tibaldi-Molteni (TM) index (notwithstanding the fact that FIM’s isentropic coordinate is ideal for PV-oriented diagnostics)
Problem:

• Tib-Mol index does not require presence of anticyclone, can be triggered by a saddle point between cutoff cyclone and main polar vortex.

• A solitary cutoff cyclone arguably does not constitute a modon-type ("Rex") block.

Proposed solution:

• Detect presence (or absence) of poleward anticyclone using streamline curvature analysis.
500mb height, day 46 of **FIM** run starting 00Z, 1-Sep-2012.
Mesh size ~30km (mesh created by 8 icosahedral refinement steps – hence “G8”), 64 $\sigma-\theta$ layers.
Analysis procedure

Write the horizontal velocity vector in natural coordinates as

$$\vec{v} = \left| \vec{v} \right| \vec{t}$$

The streamline curvature $K_s$ (the inverse of the radius of curvature) is then given by the curl of the field of unit vectors,

$$K_s = \nabla \times \vec{t}$$

Note that $K_s$ has a pole (i.e. goes to +/- infinity) in the center of a rotating air mass. This makes it easy to find circulation centers.
Easiest way to understand curvature calculation:

Start with the familiar expression for vorticity in natural coordinates:

\[ \zeta = \frac{V}{r} - \frac{\partial V}{\partial n} \]

Apply to a velocity field where \( V=1 \) everywhere.

Answer: \( \zeta = 1/r \)
Analysis procedure (cont’d)

Make catalog of $K_s$ maxima/minima (i.e. circulation centers) satisfying the following criteria:

✓ $|K_s| >$ some threshold value
✓ No nearby circulation center(s) of opposite sign
✓ In clusters of same-sign circulation centers, pick the largest

A “block” is deemed present if one of the following holds:

✓ The traditional blocking index (Tibaldi-Molteni or Pelly-Hoskins) is positive at a longitude near a $K_s$ minimum
✓ $K_s$ minimum is found poleward of a $K_s$ maximum
Example 1: 4-day G8 forecast of 500mb height starting 00Z, 19-Oct-2013. Crosses mark circulation centers deduced from curvature field\(^1\). Cyclonic [anticyclonic] curvature shown in red [blue].

\(^1\)Circulation centers must be sufficiently isolated to qualify.
Example 2: 8-day G8 forecast of 500mb height starting 00Z, 19-Oct-2013. Crosses mark circulation centers deduced from curvature field. Cyclonic [anticyclonic] curvature shown in red [blue].

source: /scratch1/portfolios/BMC/fim/bleck/2013101900/fim8_out_h500.nc
The blocking index is traditionally displayed in a Hovmøller diagram, i.e., in longitude-time space.

To display multiple forecast runs with overlapping time ranges in a single plot, we use verification time as ordinate and use color to indicate the lead time of a given forecast.

In the following 2 frames, color coding of lead time is demonstrated for a single model run. Multiple runs will be shown later.
Diamonds: curvature dipoles meeting meridional alignment criteria

Crosses: points where index > 0 and spacing/isolation criteria are met

Day 8

Day 4

Initial time, yymmddhh

13101900

source:/scratch1/portfolios/BMC/fim/bleck/2013101900/fim8_out_h500.nc
Example 3: 10-day G6 prediction starting at 00Z, 26-Oct-2013, showing two modon-like blocking patterns. Interestingly, neither block spawns a positive Tibaldi-Molteni index. The Western European block persists for 5 days... see next slide.
Abscissa: longitude. Ordinate: verification time. Color: forecast lead time. The “modified” index is obtained by applying the curvature filter to the original index. Cold colors overlaying warm colors indicate successful long-range prediction of a block.
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Concluding Remarks

- The streamline curvature ($K_s$) field is simple to analyze and is convenient for objectively detecting circulation centers.
- The $K_s$ field allows us to detect “false positives” in traditional blocking diagnostics.
- The $K_s$ field is particularly effective in objectively detecting modon-like blocking patterns.
- The $K_s$ tool is suited for both Tibaldi-Molteni- and Pelly-Hoskins-based blocking index studies.
- “Improved algorithm”? Statistically, improvements are minor. The TibMol index is quite reliable as it is.