An improved algorithm for detecting blocking events

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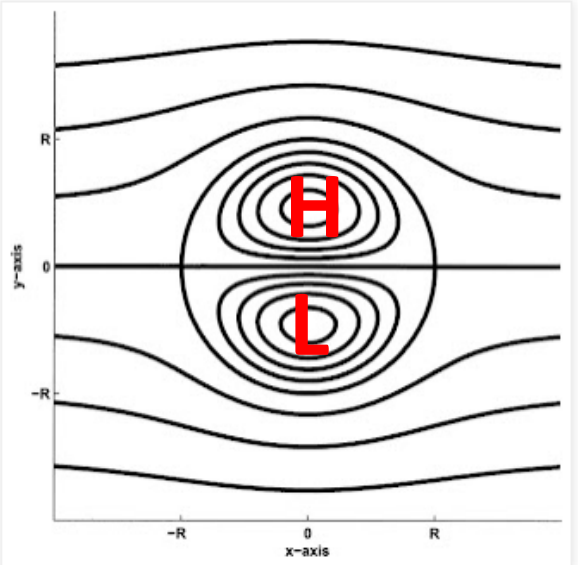
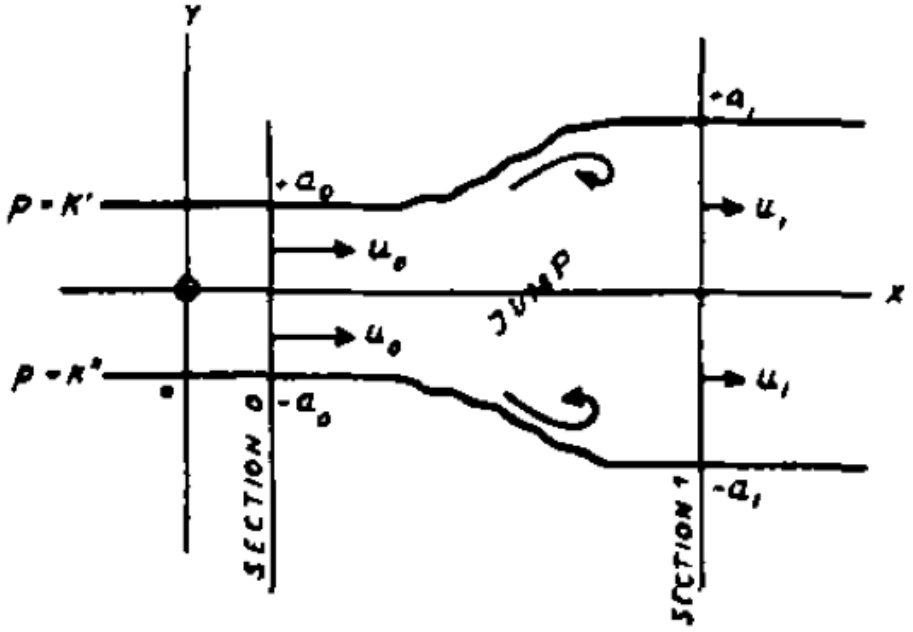
Introduction

- 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.

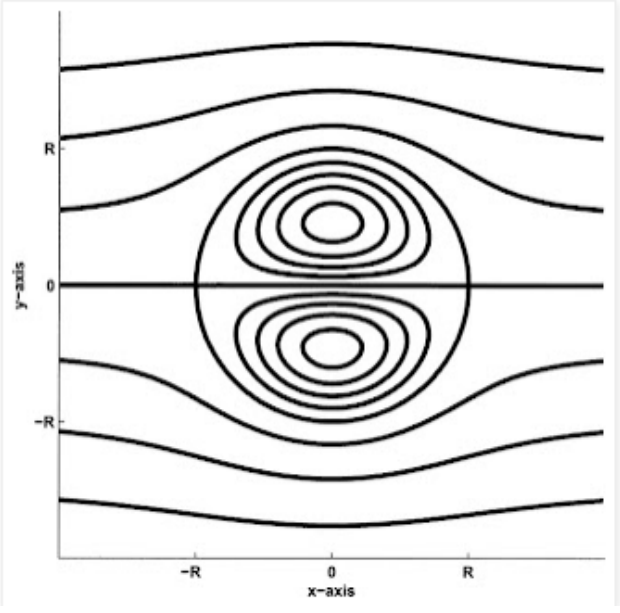
Modons are exact solutions of the quasi-geostrophic shallow-water equations on a beta plane and appear to have attractor-like properties.

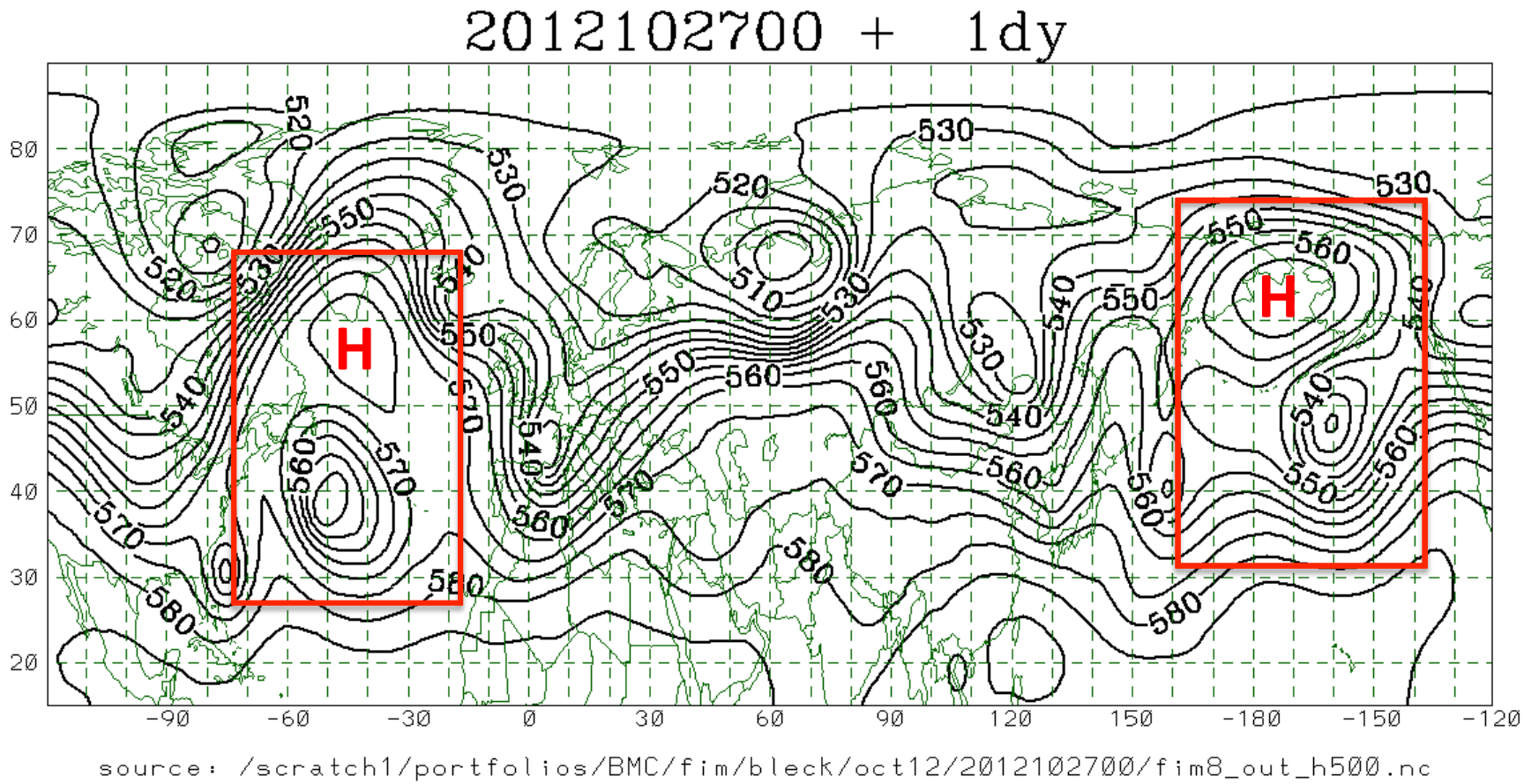


Rex, D. F., 1950. Blocking Action in the Middle Troposphere and its Effect upon Regional Climate. I. An Aerological Study of Blocking Action. *Tellus,* **2**, 196-211.



Flierl, G.R., Larichev, V.D., McWilliams, J.C. and Reznik, G.M., 1980. The dynamics of baroclinic and barotropic solitary eddies. *Dyn. Atmos. Oceans*, **5**, 1-41.




2012102700 + 1dy
H
H
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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)

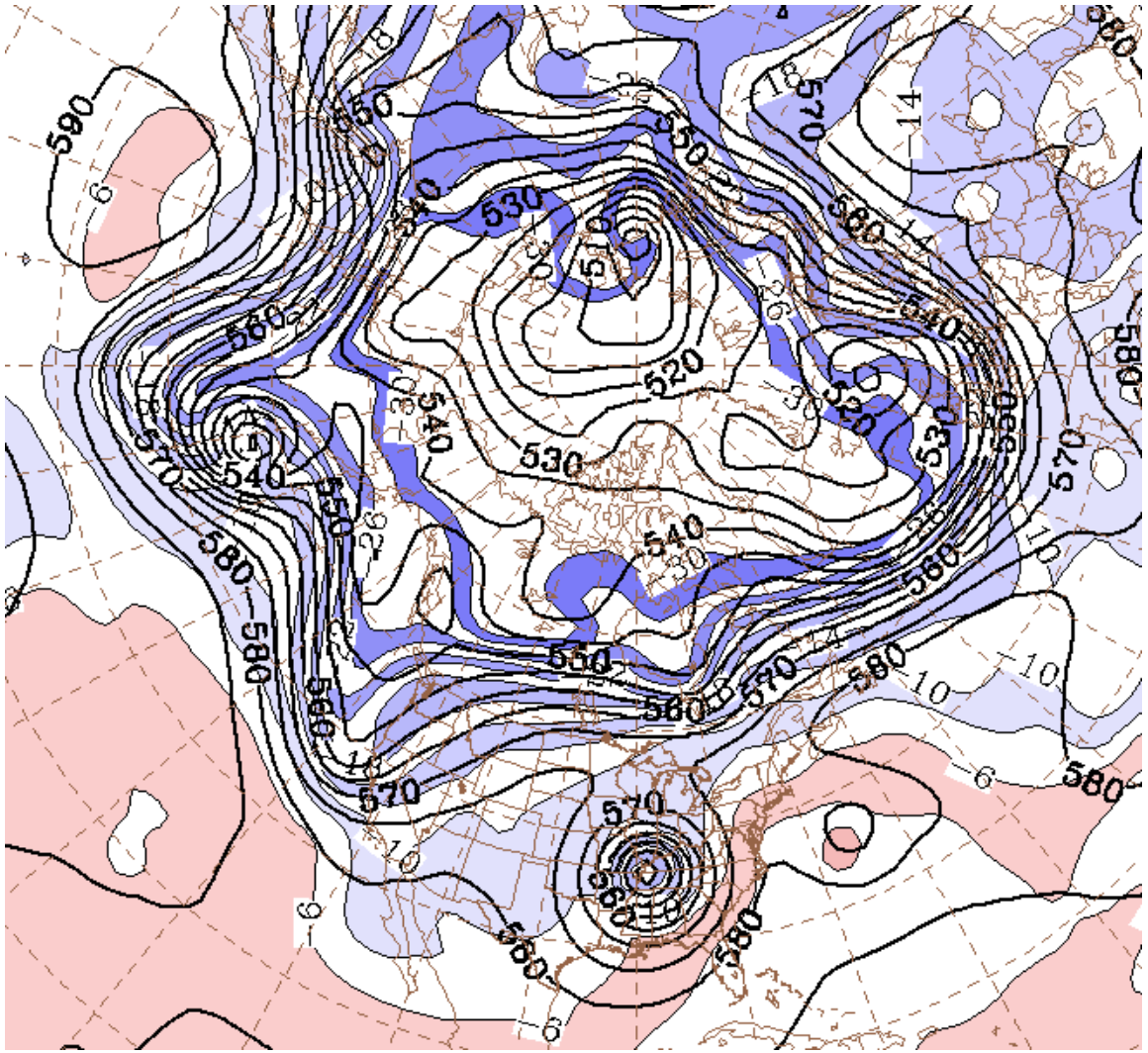
Problem:

- 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 refine-ment 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

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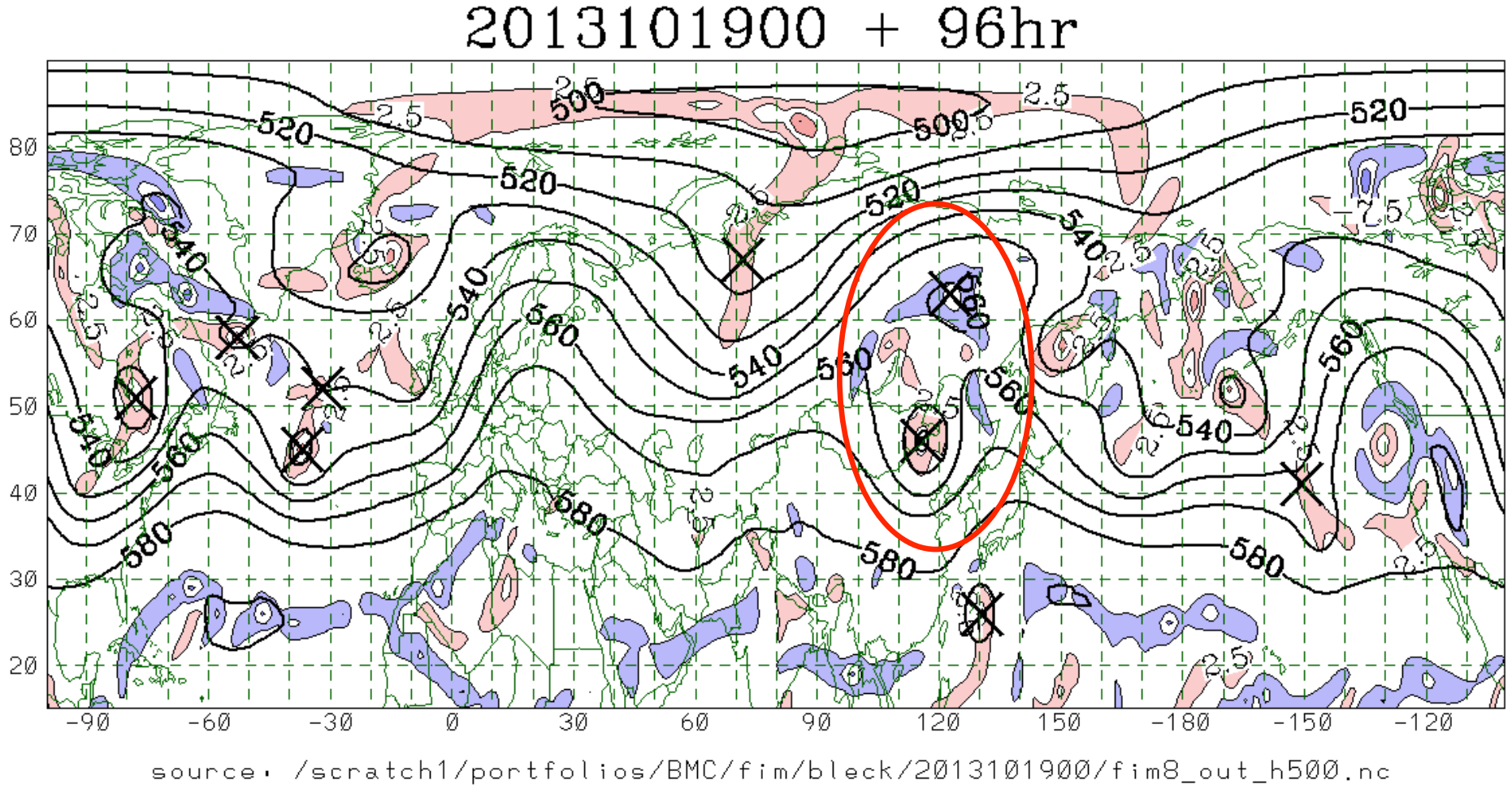
A "block" is deemed present if one of the following holds:

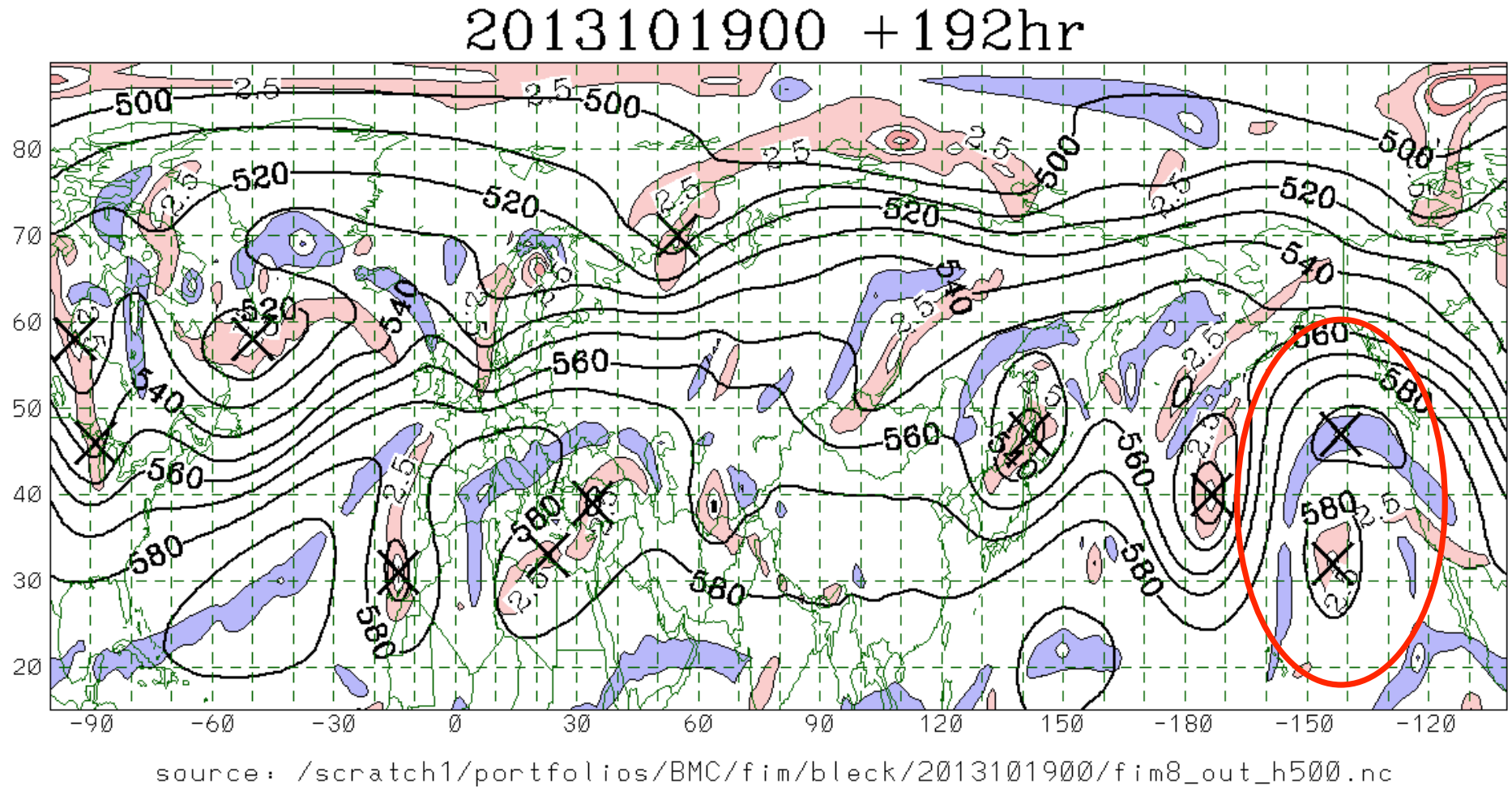
- ✓ The traditional blocking index (Tibaldi-Molteni or Pelly-Hoskins) is positive at a longitude near a K_s *minimum*
- ✓ A K_s *minimum* is found poleward of a K_s *maximum*

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.

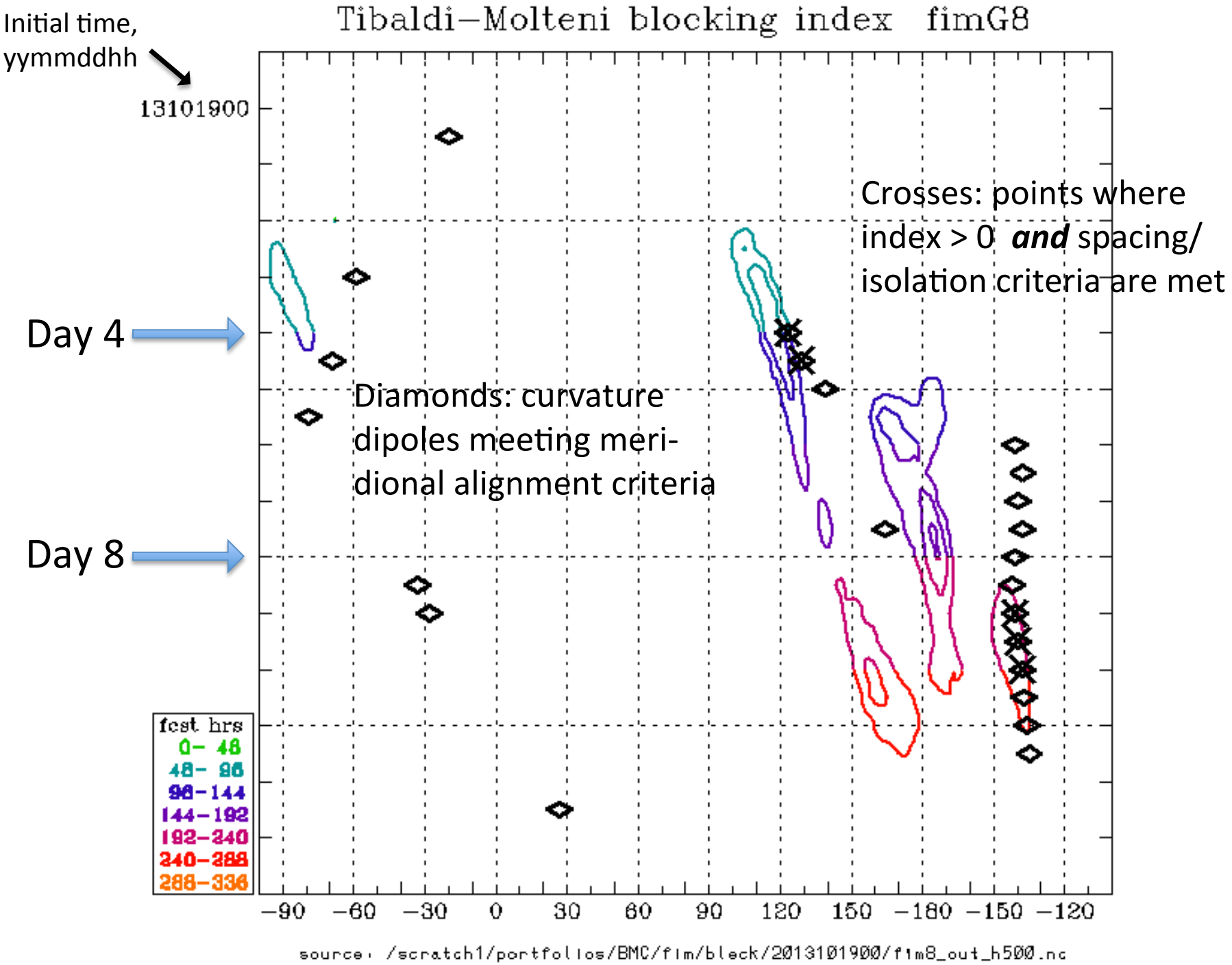
Example 2: 8-day G8 forecast of 500mb height starting 00Z, 19-Oct-2013. Crosses mark circulation centers deduced from curvature field. Cyclonic [anticyclonic] curvature shown in red [blue].



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 singe model run. Multiple runs will be shown later.


Initial time, yymmddhh
Tibaldi–Molteni blocking index fimG8
13101900
Day 4
Day 8
Crosses: points where index > 0 and spacing/ isolation criteria are met
Diamonds: curvature dipoles meeting meri- dional alignment criteria
fcst hrs
0- 48
48- 96
96-144
144-192
192-240
240-288
288-336
-90 -60 -30 0 30 60 90 120 150 -180 -150 -120
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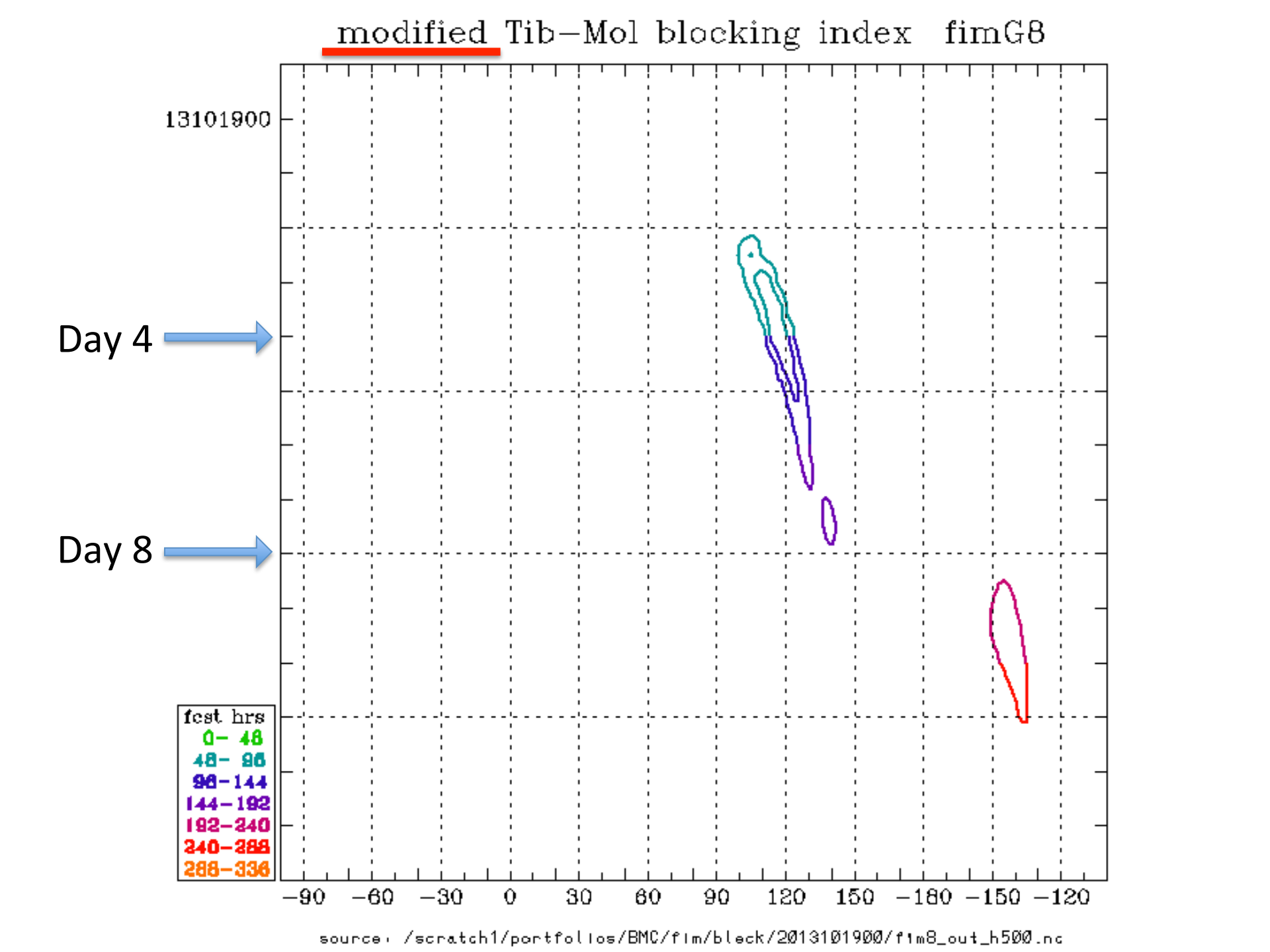
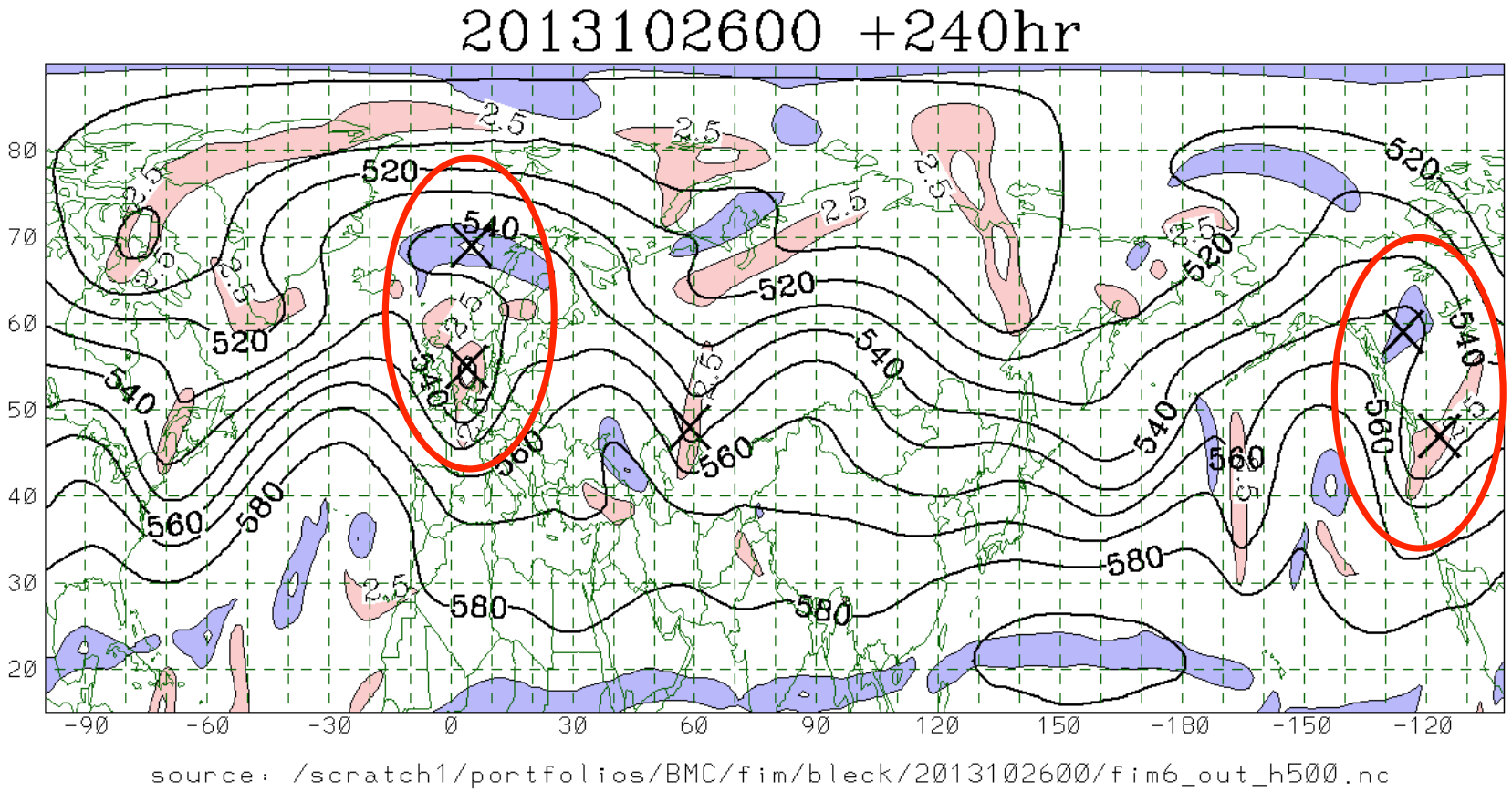
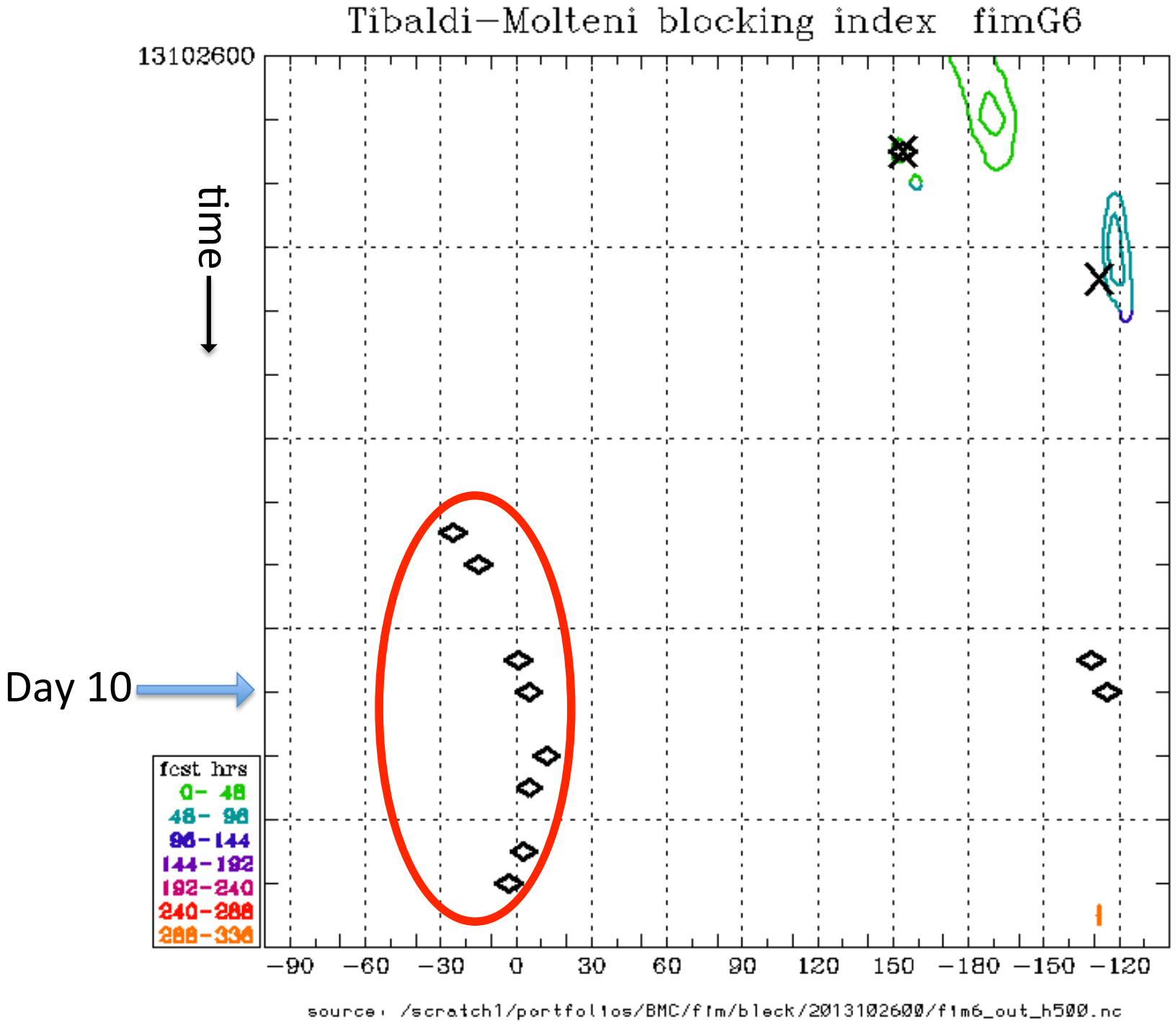
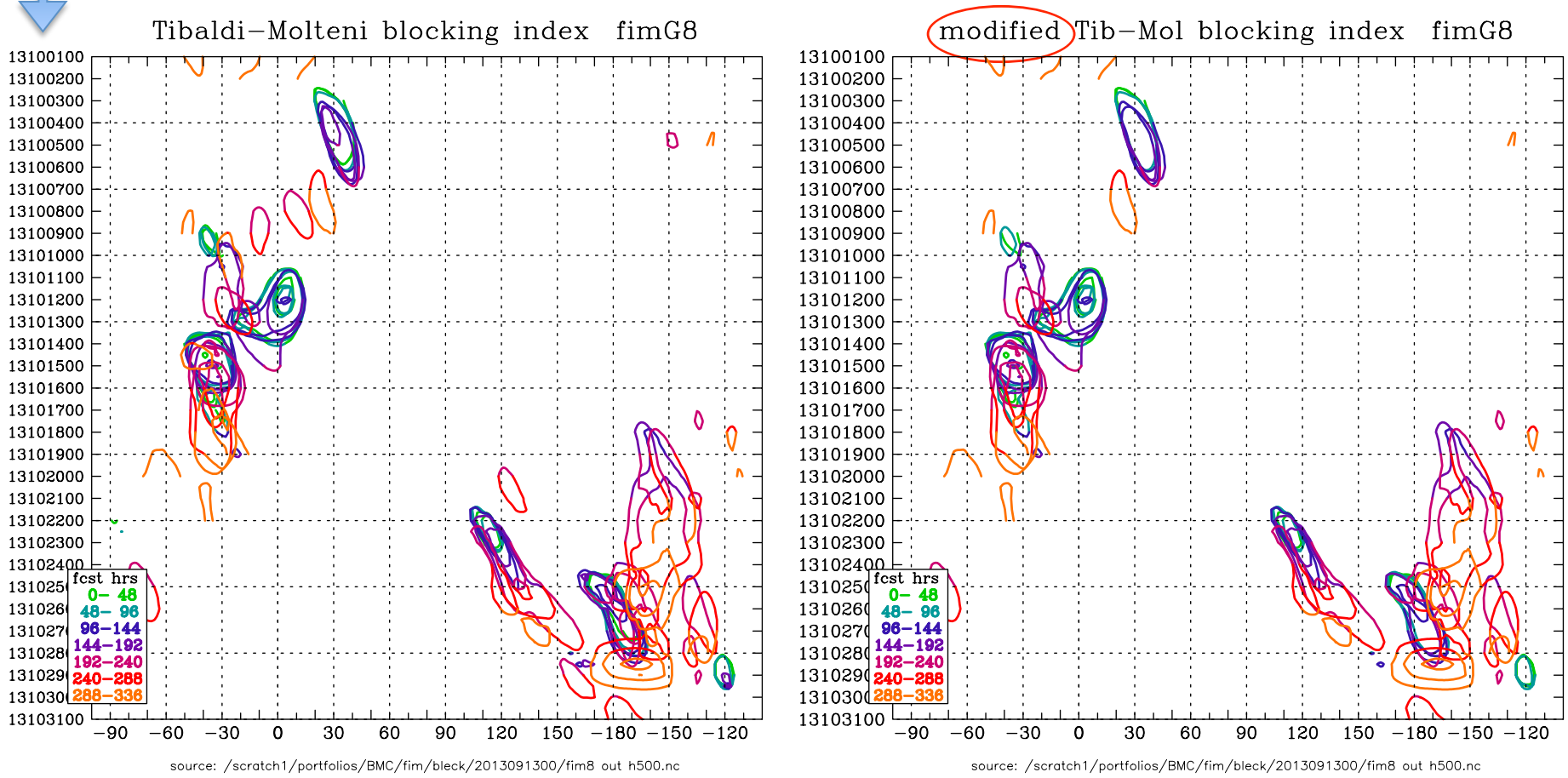

modified Tib−Mol blocking index fimG8
13101900
Day 4
Day 8
fcst hrs
0- 48
48- 96
96-144
144-192
192-240
240-288
288-336
−90 −60 −30 0 30 60 90 120 150 −180 −150 −120
source: /scratch1/portfolios/BMC/fim/bleck/2013101900/fim8_out_h500.nc

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.



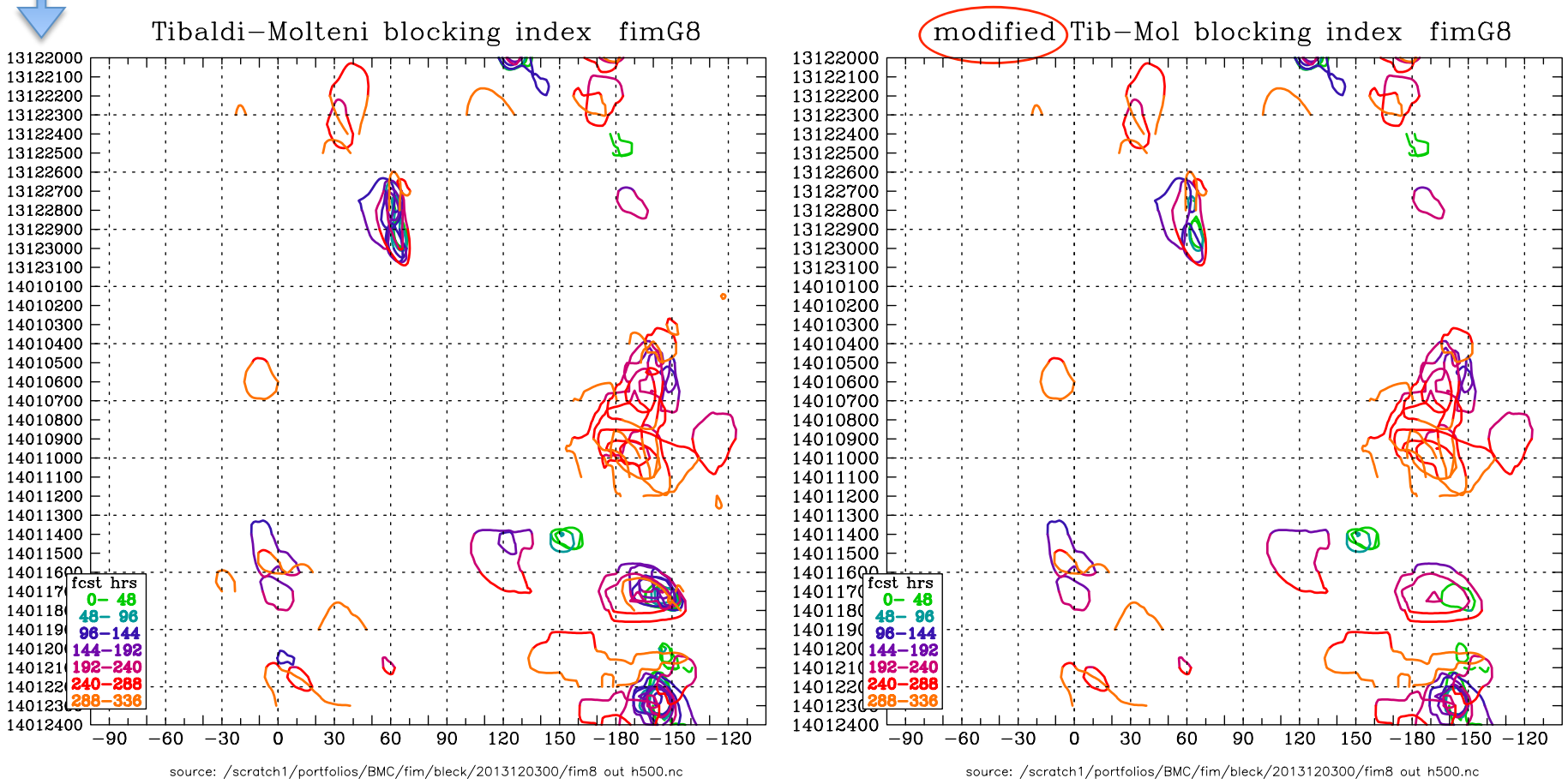

Tibaldi–Molteni blocking index fimG6
13102600
time
Day 10
fcst hrs
0- 48
48- 96
96-144
144-192
192-240
240-288
288-336
−90 −60 −30 0 30 60 90 120 150 −180 −150 −120
source: /scratch1/portfolios/BMC/fim/bleck/2013102600/fim6_out_h500.nc

1 - 31 Oct 2013



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.

20 Dec - 24 Jan 2014



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.

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.