Flows associated with emerging active regions

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Part 1: Motivations

Motivations

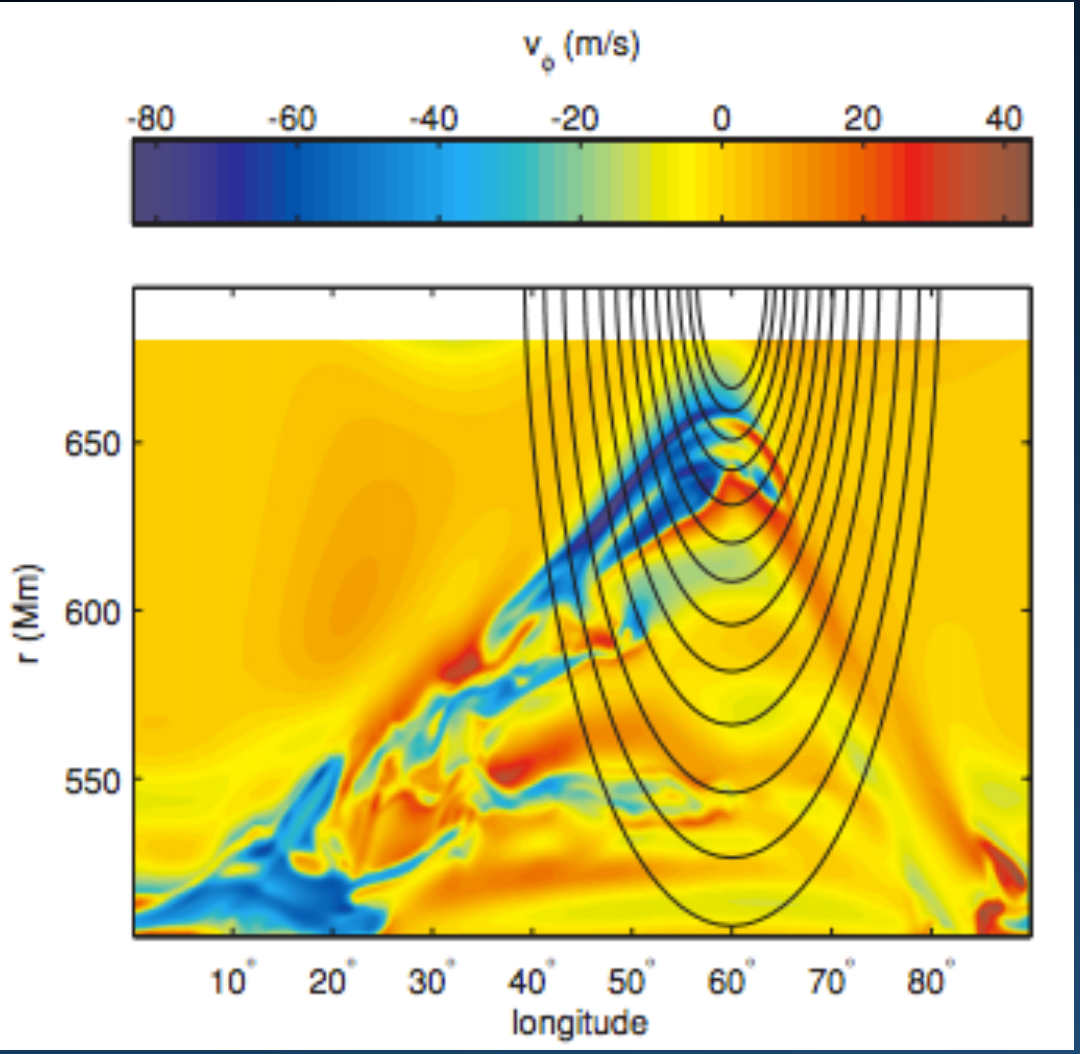
- How does active region emergence work?
  - Where do AR come from?
  - How do emerging AR interact with convection?
  - What are the flows associated with AR?
- Constrain models
  - Potentially rule out certain models (rising flux tubes?)
  - Converging flows associated with AR play a role in some dynamo models (e.g. Cameron & Schuessler, 2012)

Past (helioseismology) studies

- Pre-emergence case studies:
  - Braun (1995, Hankel analysis)
  - Jensen et al. (2001, time-distance)
  - Hartlep et al. (2011, acoustic power)
  - Ilonidis et al. (2011, time-distance)
  - Many others …
- Statistical studies
  - Komm et al. (2009, 2011, rings, 100s of regions)
  - Birch et al. (2013, holography, ~100 regions one day before emergence)
- Open questions remain

One model for what we might see

(Fan 2008, 3d simulation ``LNT", 10^{23} Mx)



- Based on this model, we estimated how many AR we need to average before we can see something with helioseismology
- Answer: about 100 AR

Birch, Braun, Fan (2010)

Part 2: measurements

HMI Data selection

- Presented by Hannah on Tuesday
- Additional constraints:
  - Less then 50 deg from central meridian
  - Duty cycle > 90%
  - Only “nice” emergences
- Result: subsample of about 60 emerging AR

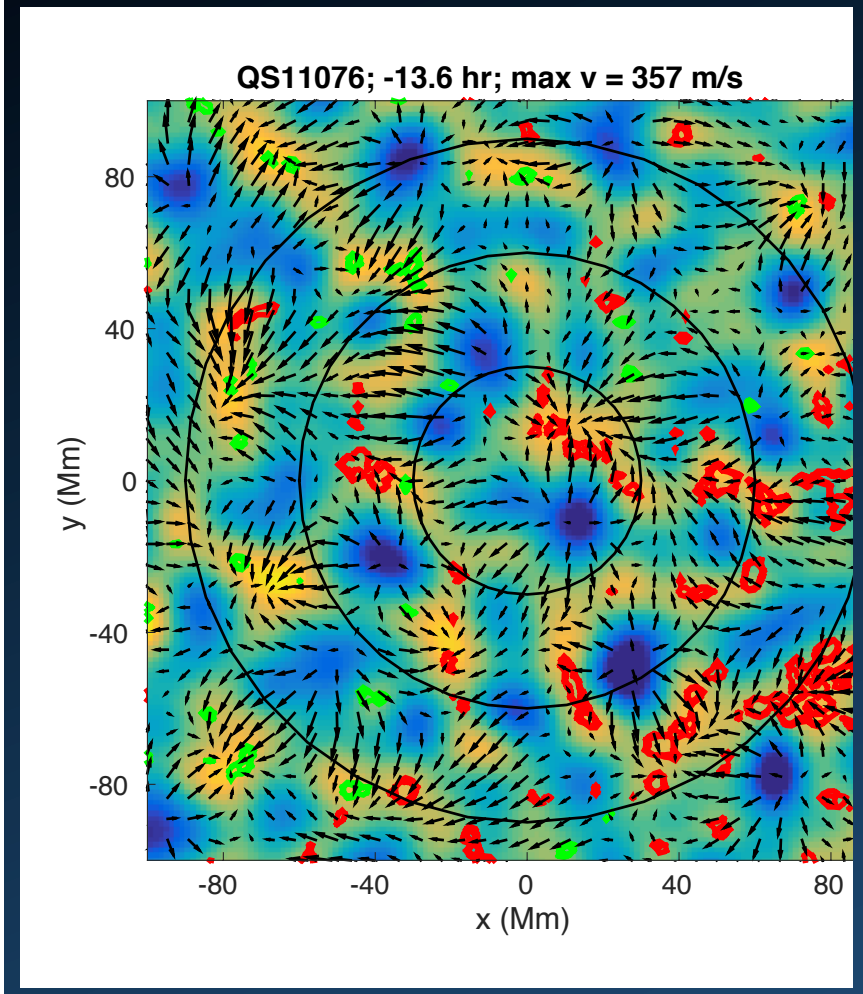
Helioseismic Holography

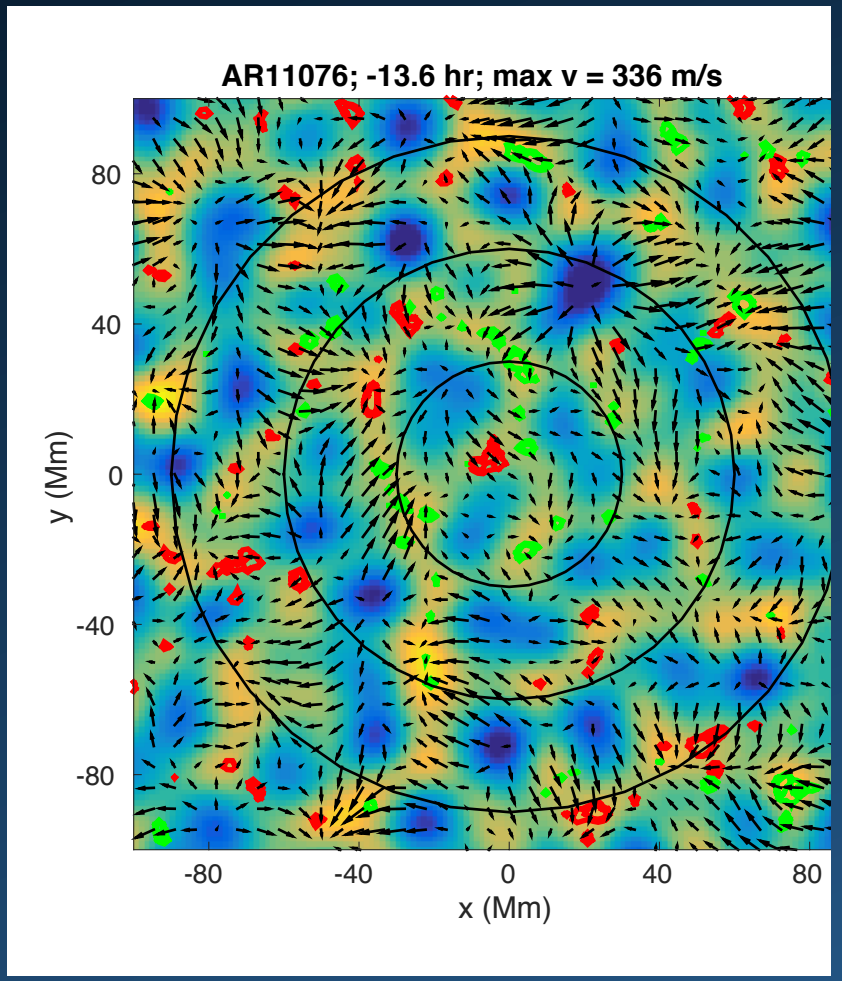
- This talk: surface focusing measurements (lower turning point 3 Mm)
- Strategy:
  - Carry out helioseismology for emerging AR and quiet Sun control regions
  - find clear signals first and then think about inversions

Local Correlation Tracking using HMI intensity images

- Fisher & Welsch code (FLCT)
- Continuum intensity images from HMI
- Track and remap
- Correlation tracking at 45s cadence
- (for today) average together the flow maps over the same time periods as the seismology maps

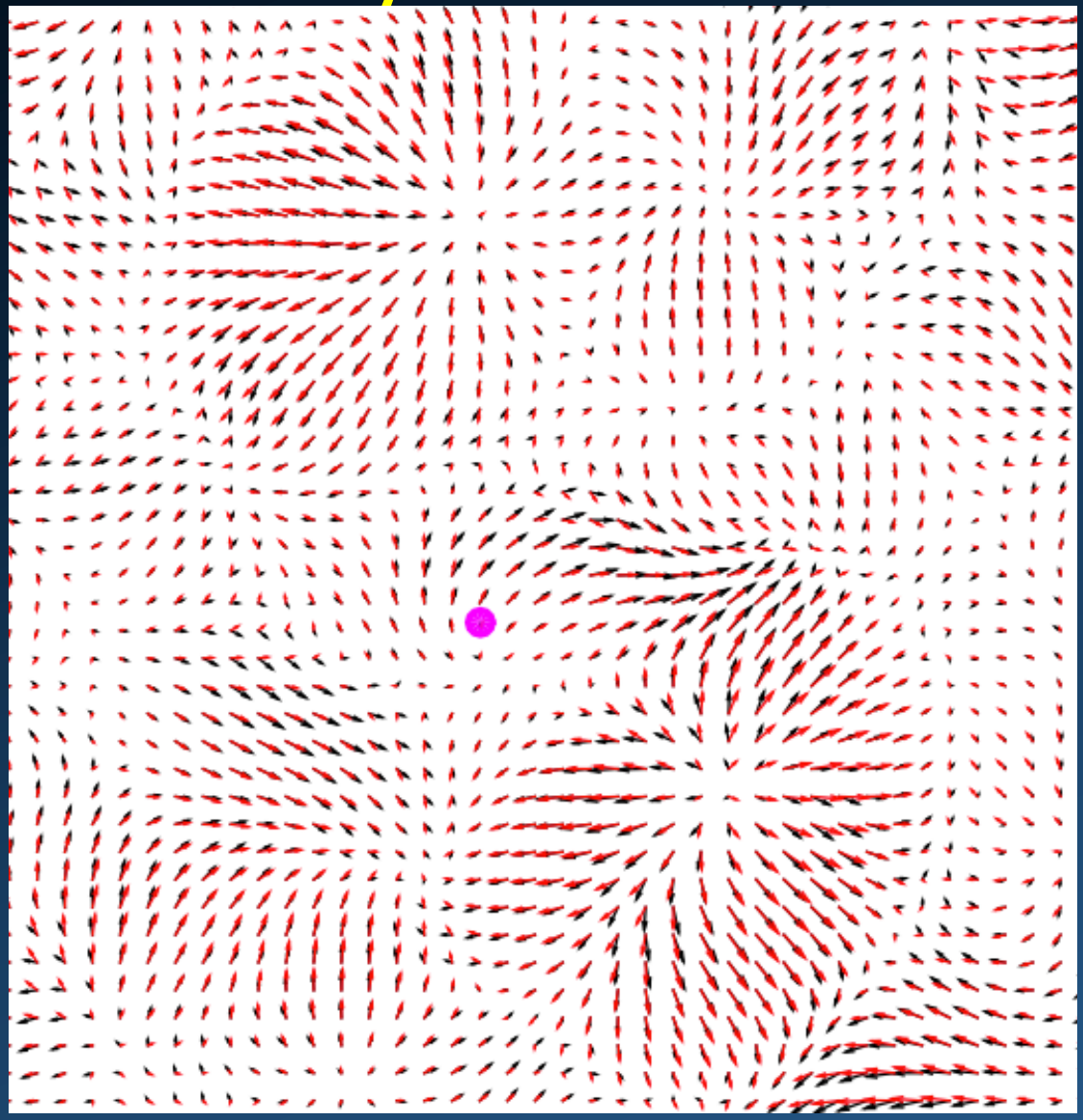
Supergranulation is the dominant signal in the seismology measurements





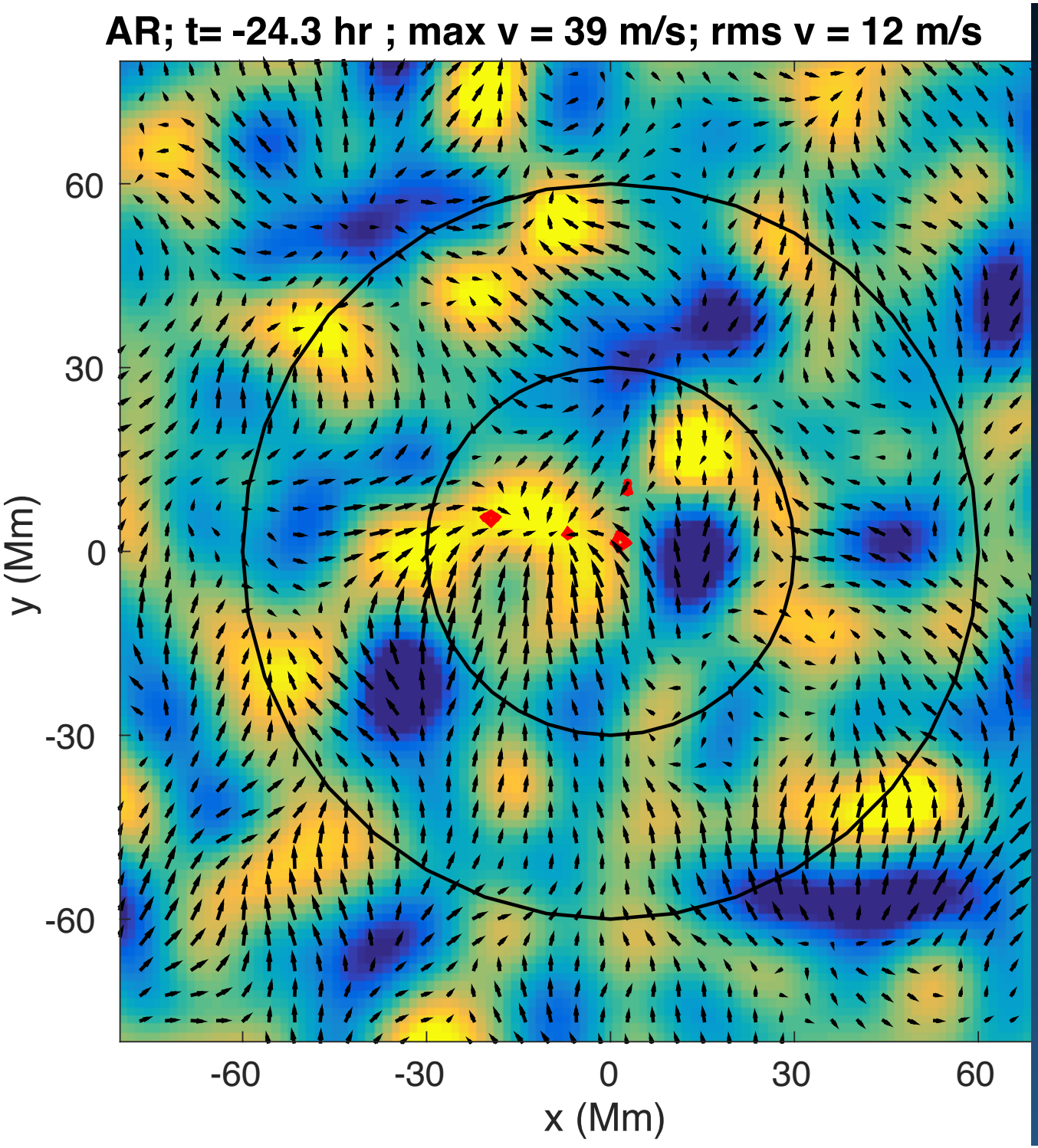
Blue = divergence; yellow= convergence. Contours of LoS B (20, 40 gauss)

Near-surface seismology agrees reasonably well with the LCT



No clear signal in individual maps

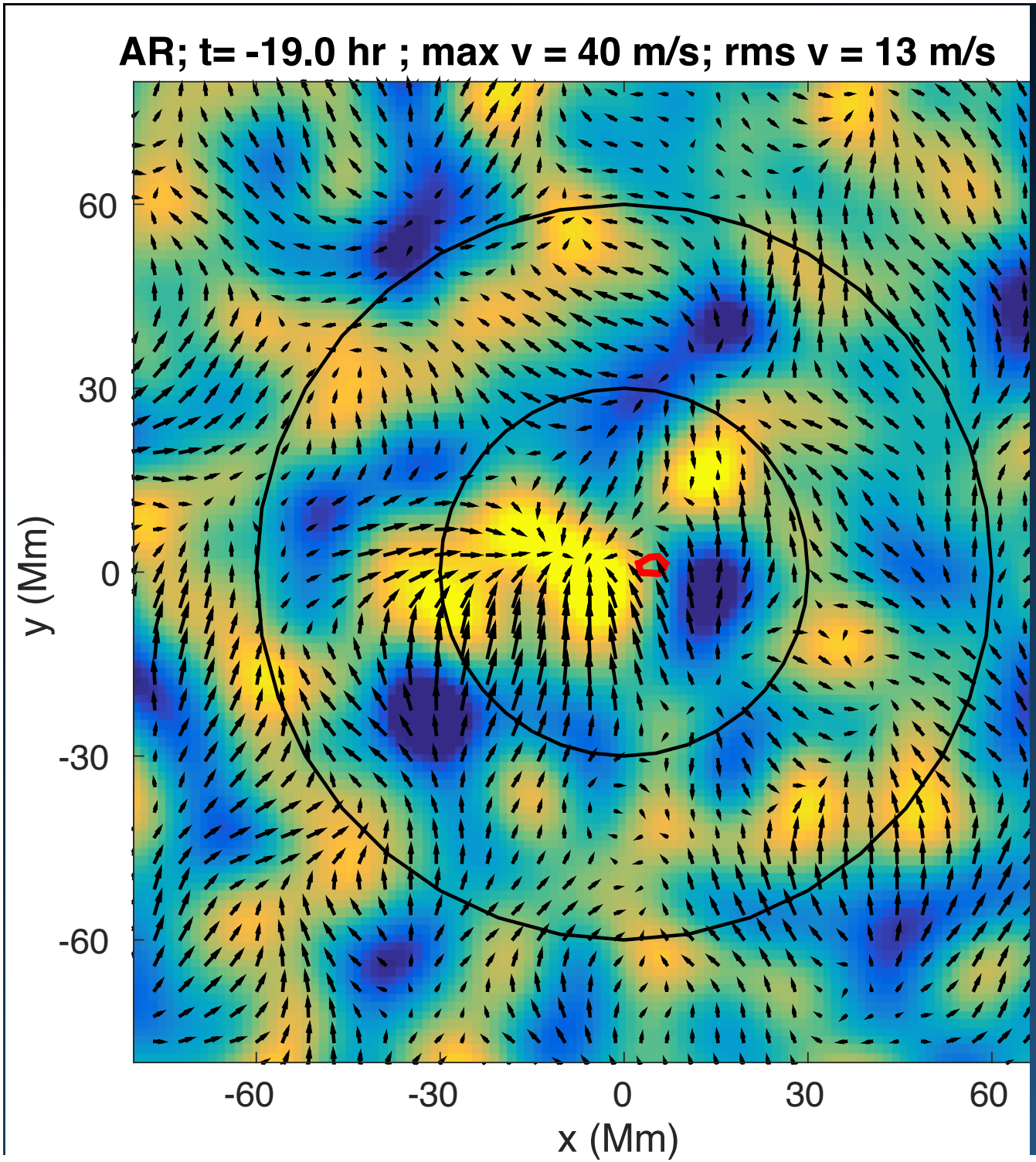
Next step: ensemble averages
(about 60 regions)



Seismology
Average over AR
T = -24 hours

Blue = diverging flow

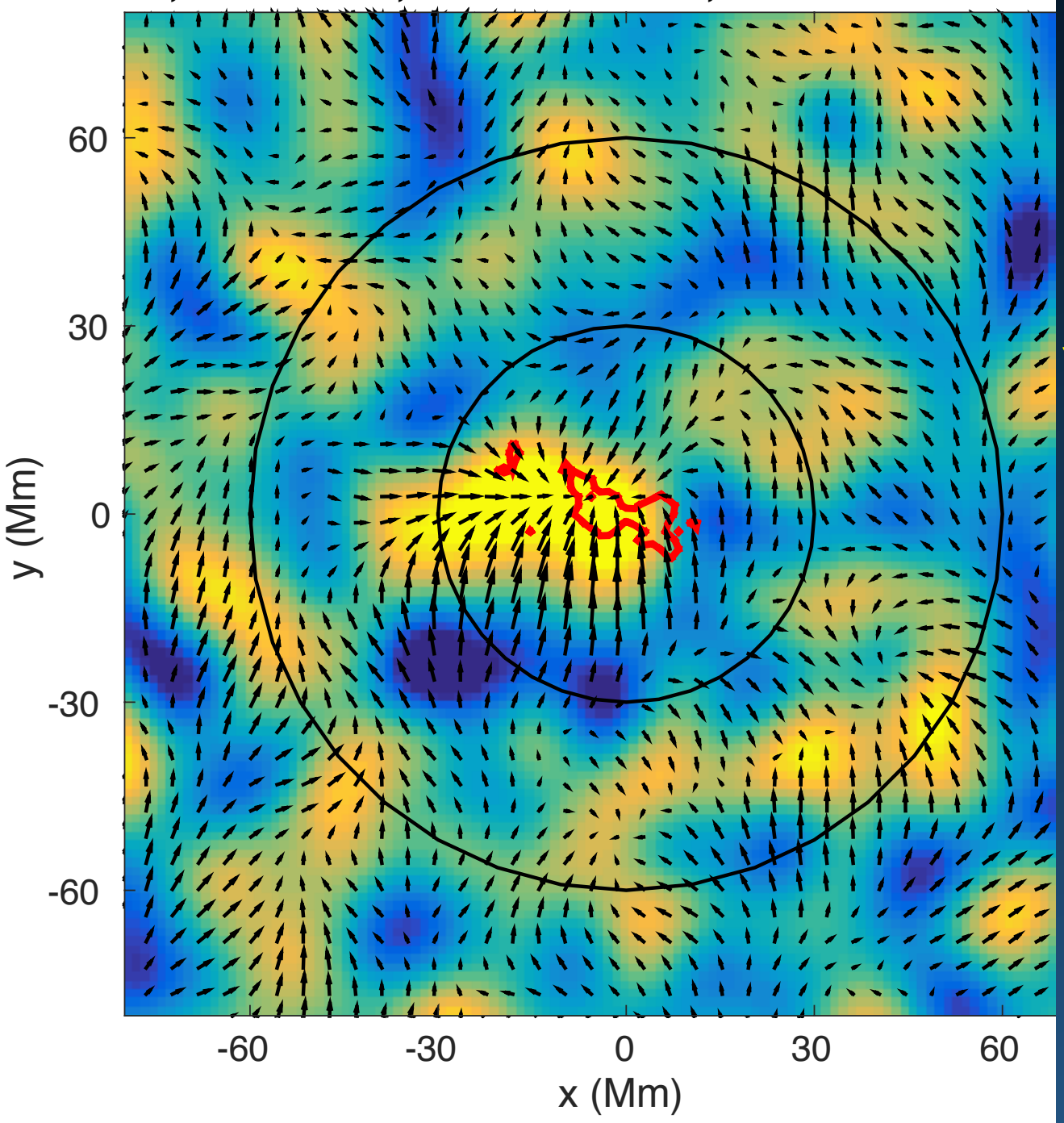
Yellow = converging



Seismology
Average over AR
T = -19 hours

Blue = diverging flow

Yellow = converging

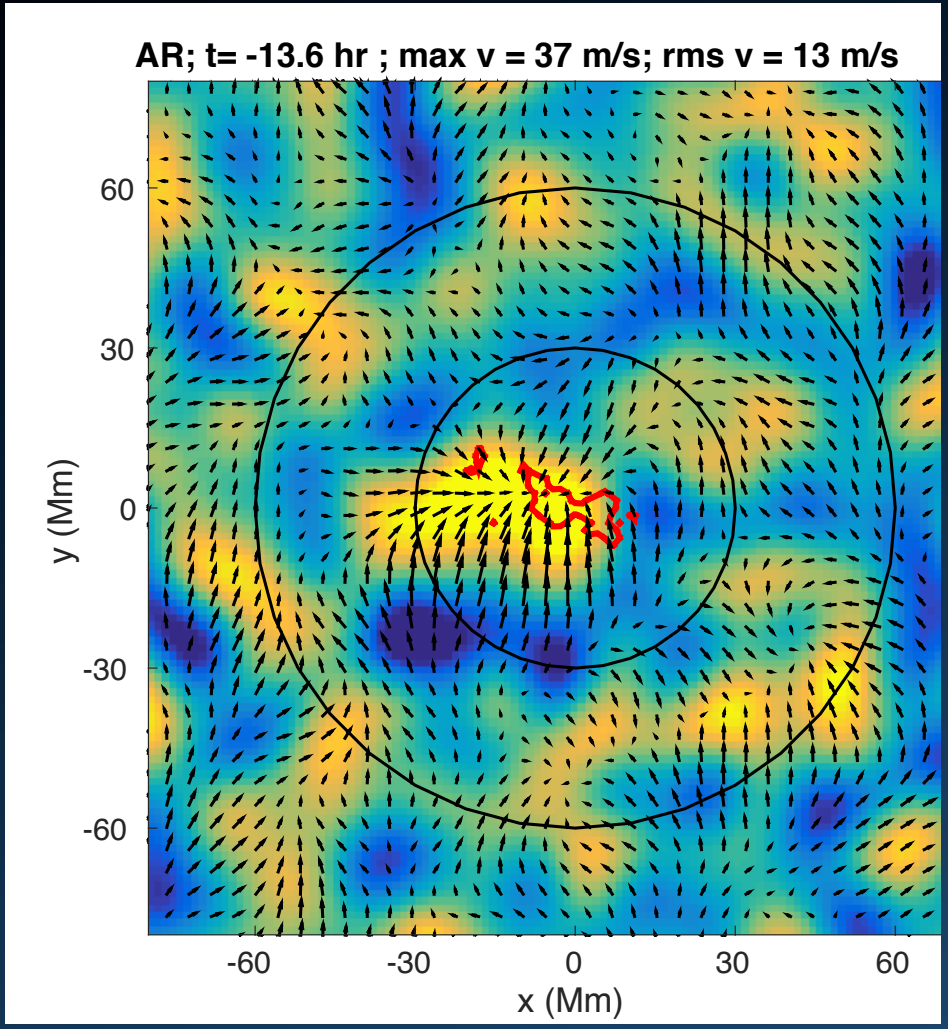


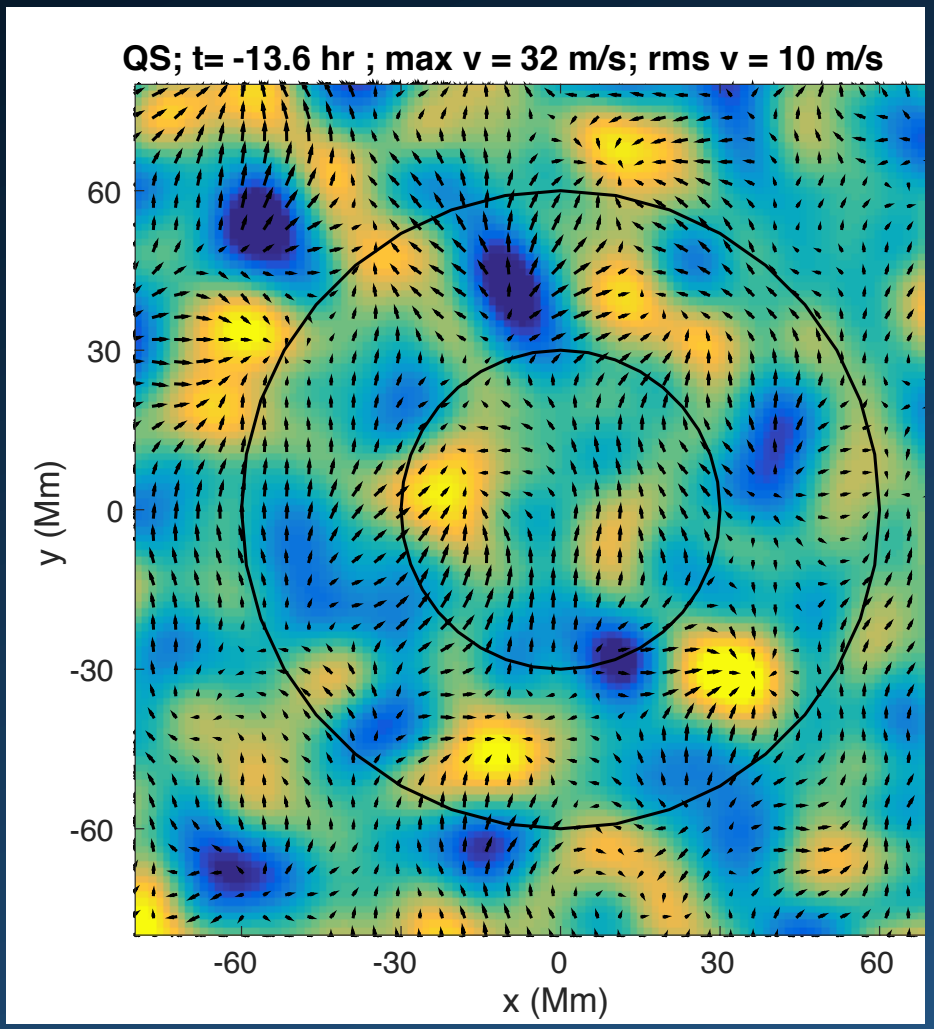
Seismology
Average over AR
T = -14 hours

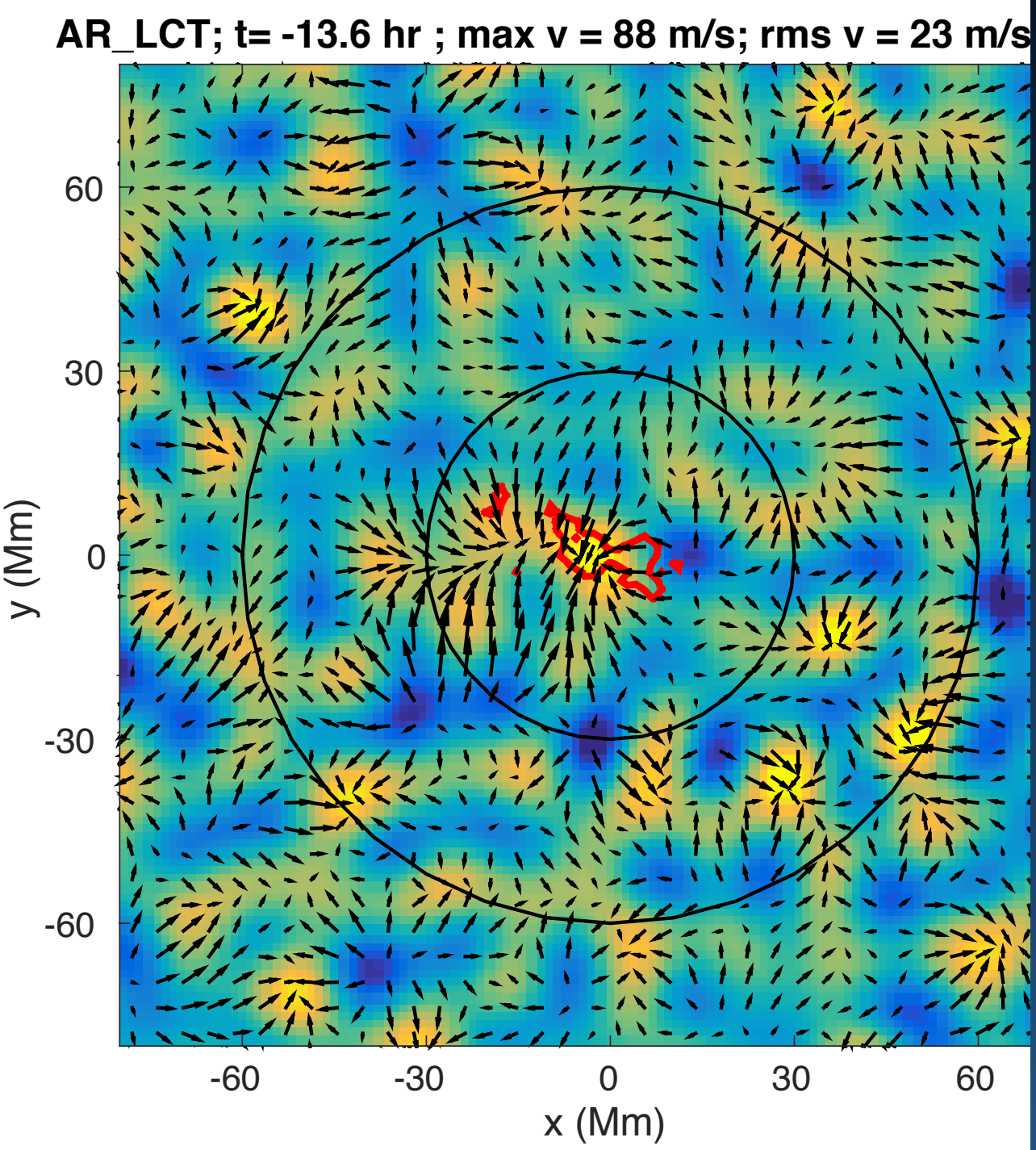
Blue = diverging flow

Yellow = converging

Red countour = |LoS B|
(20 gauss)


AR; t= -13.6 hr ; max v = 37 m/s; rms v = 13 m/s
60
30
0
-30
-60
y (Mm)
-60
-30
0
30
60
x (Mm)


QS; t= -13.6 hr ; max v = 32 m/s; rms v = 10 m/s
60
30
0
-30
-60
y (Mm)
-60
-30
0
30
60
x (Mm)

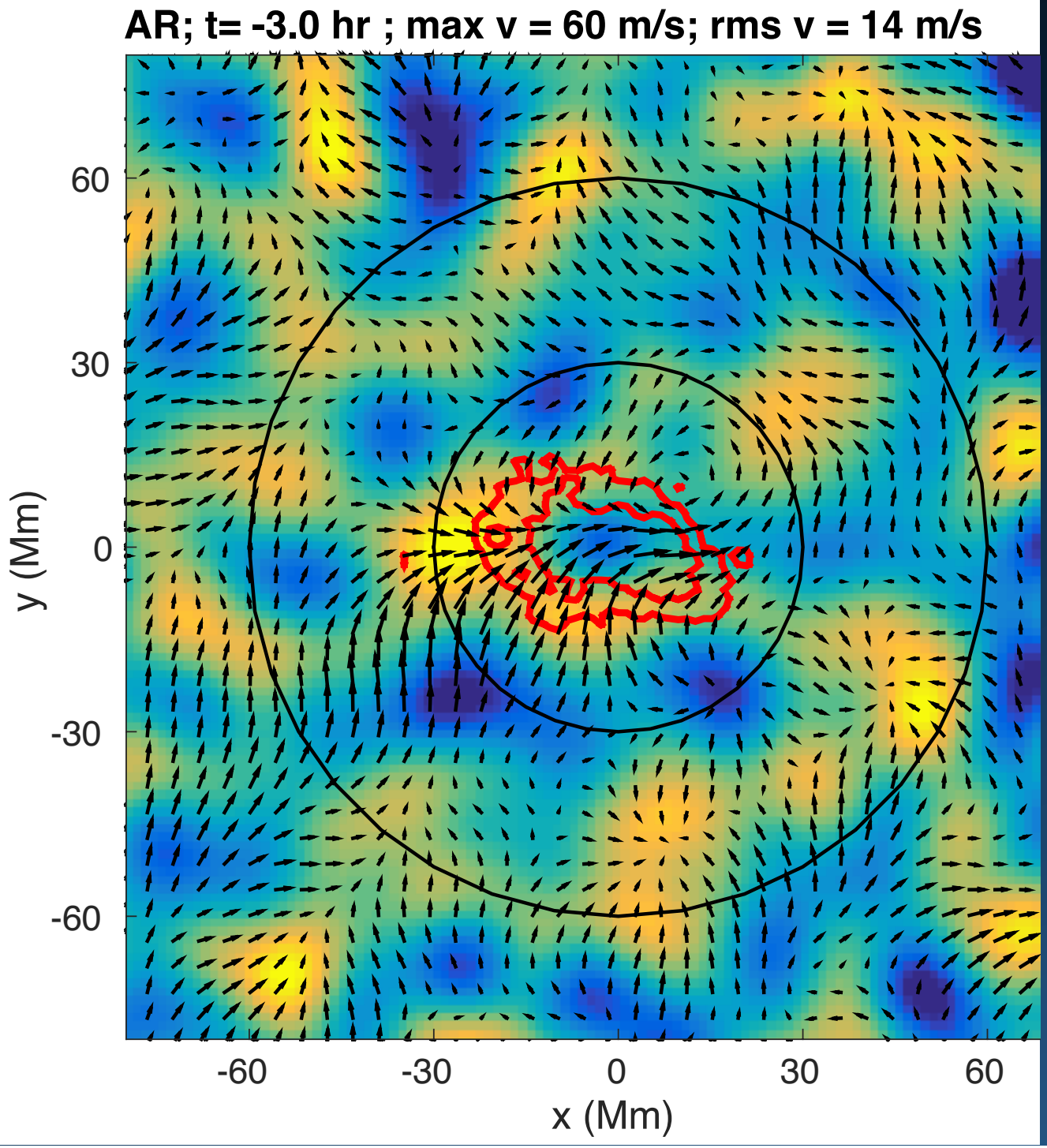


LCT
Average over AR
T = -14 hours

Blue = diverging flow

Yellow = converging

Red contour = |LoS B|
(20 gauss)



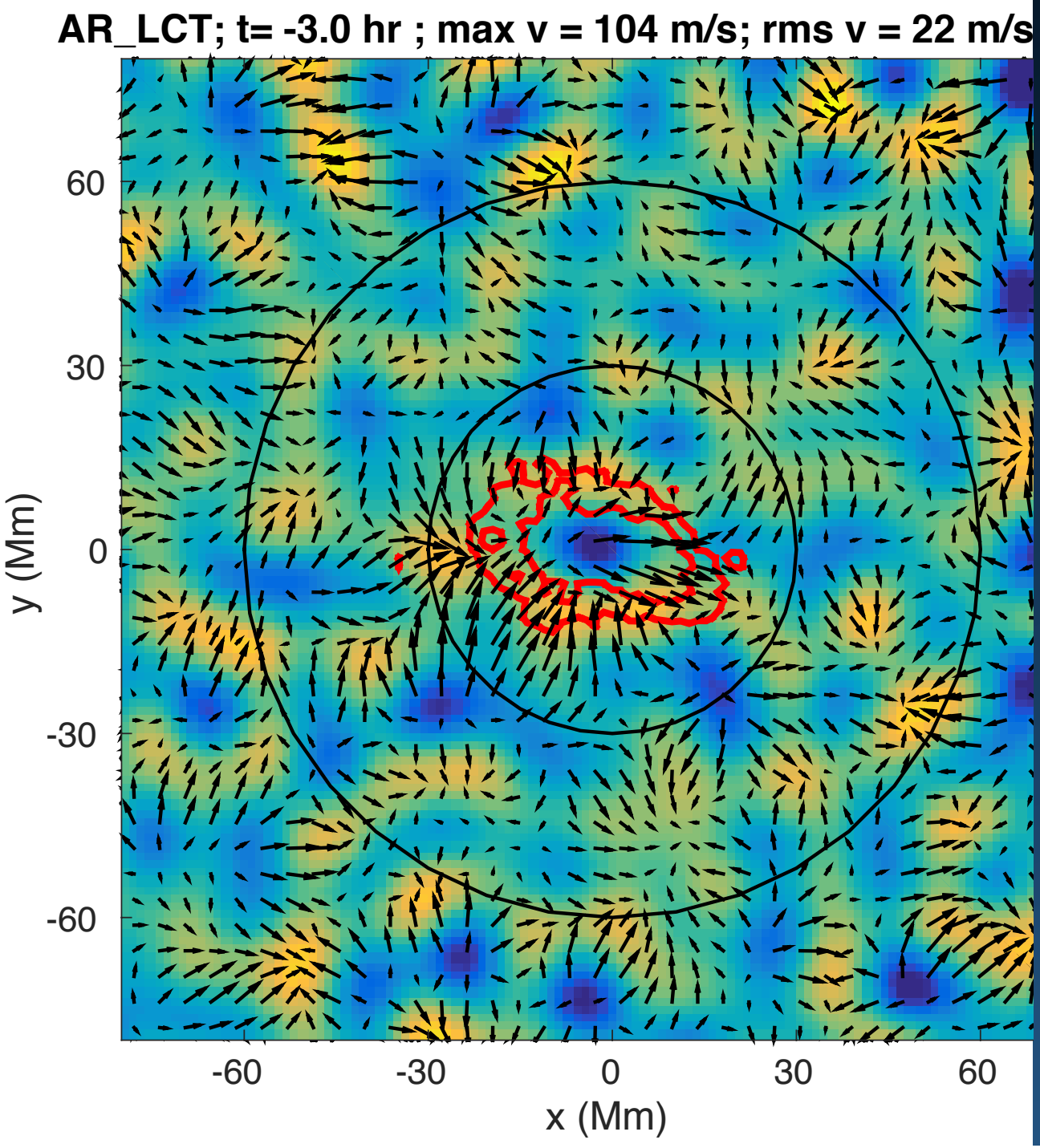
Seismology
Average over AR
T = -3 hours

Blue = diverging flow

Yellow = converging

Red contours = |LoS B|
(20, 40 gauss)

Beginning to see to divergence at emergence location



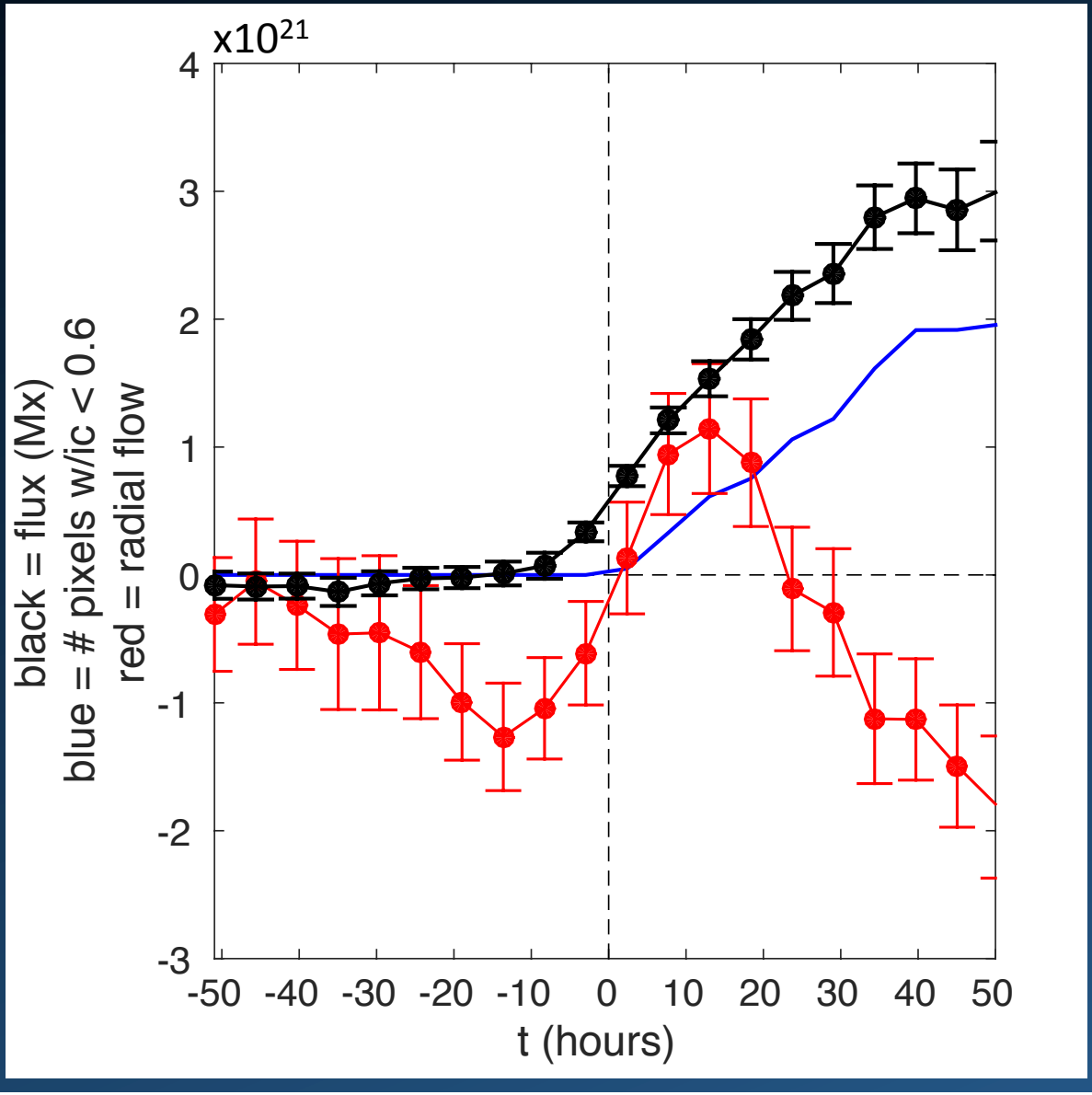
LCT
Average over AR
T = -3 hours

Blue = diverging flow

Yellow = converging

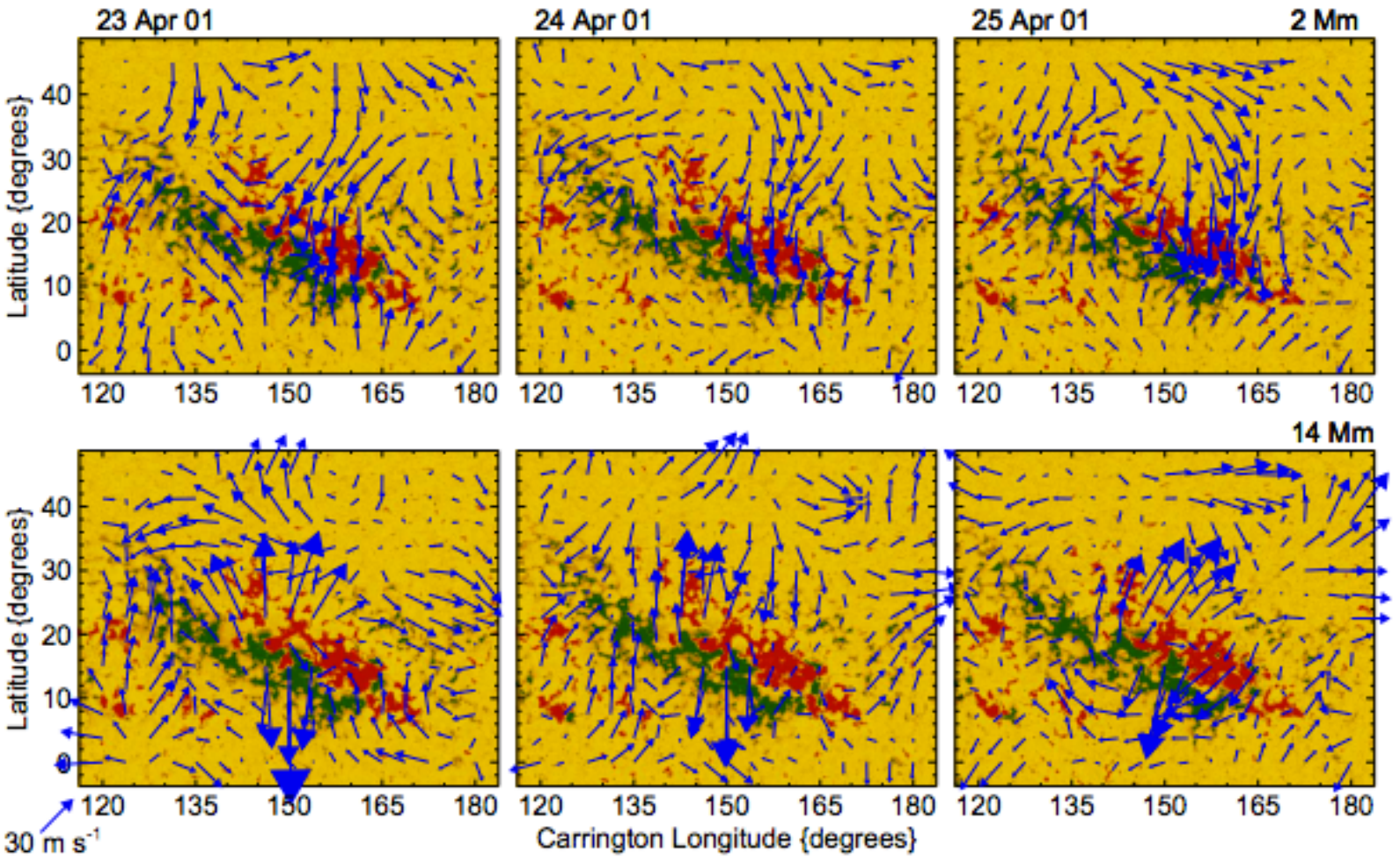
Red contours = |LoS B|
(20, 40 gauss)

Converging flow before emergence



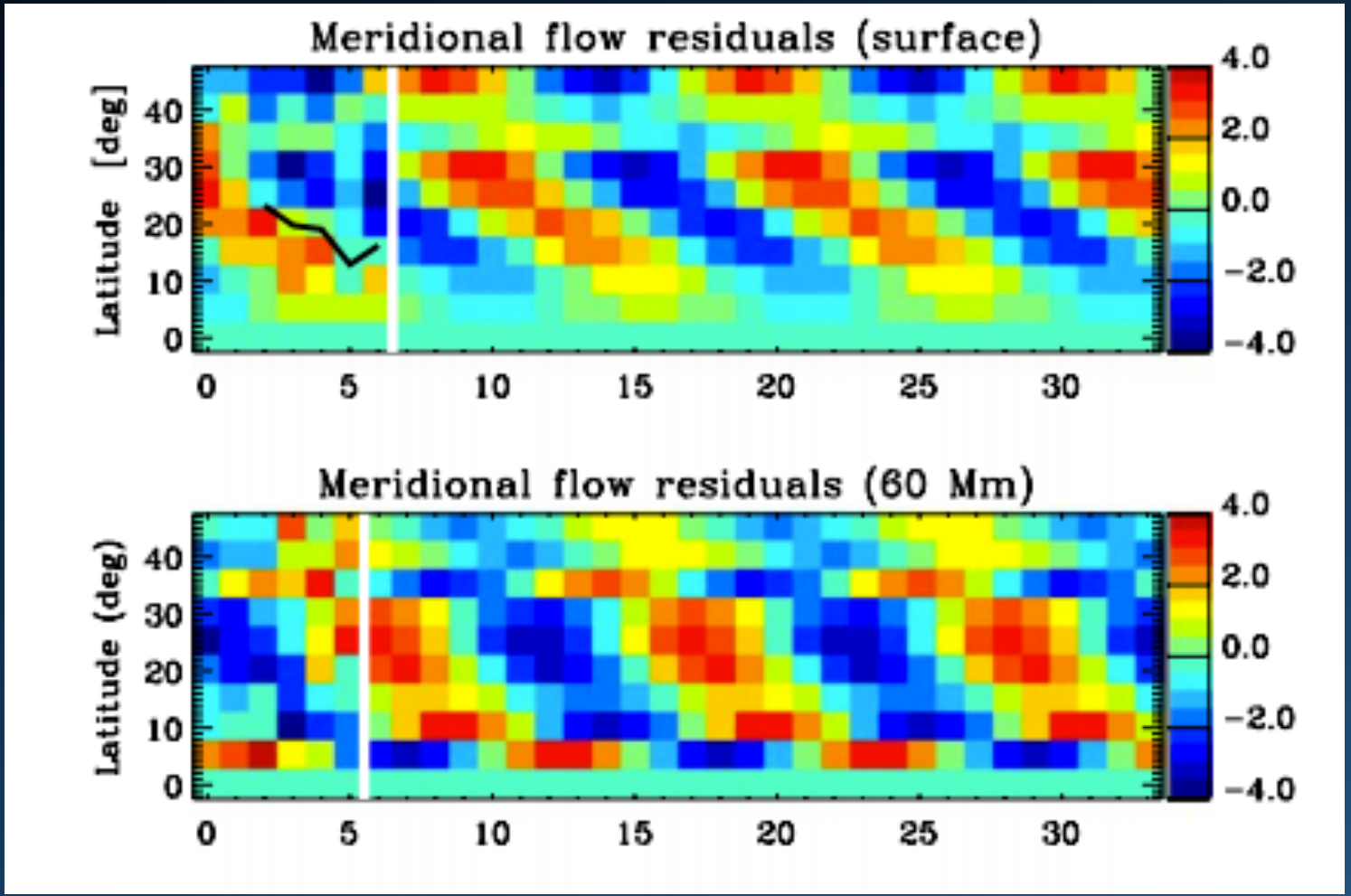
Small aside: after emergence

Converging flows towards AR at surface; diverging flows at depth



From ring diagrams. Hindman et al 2009; Haber et al. 2004

Meridional flow varies with solar cycle: Converging flow near surface



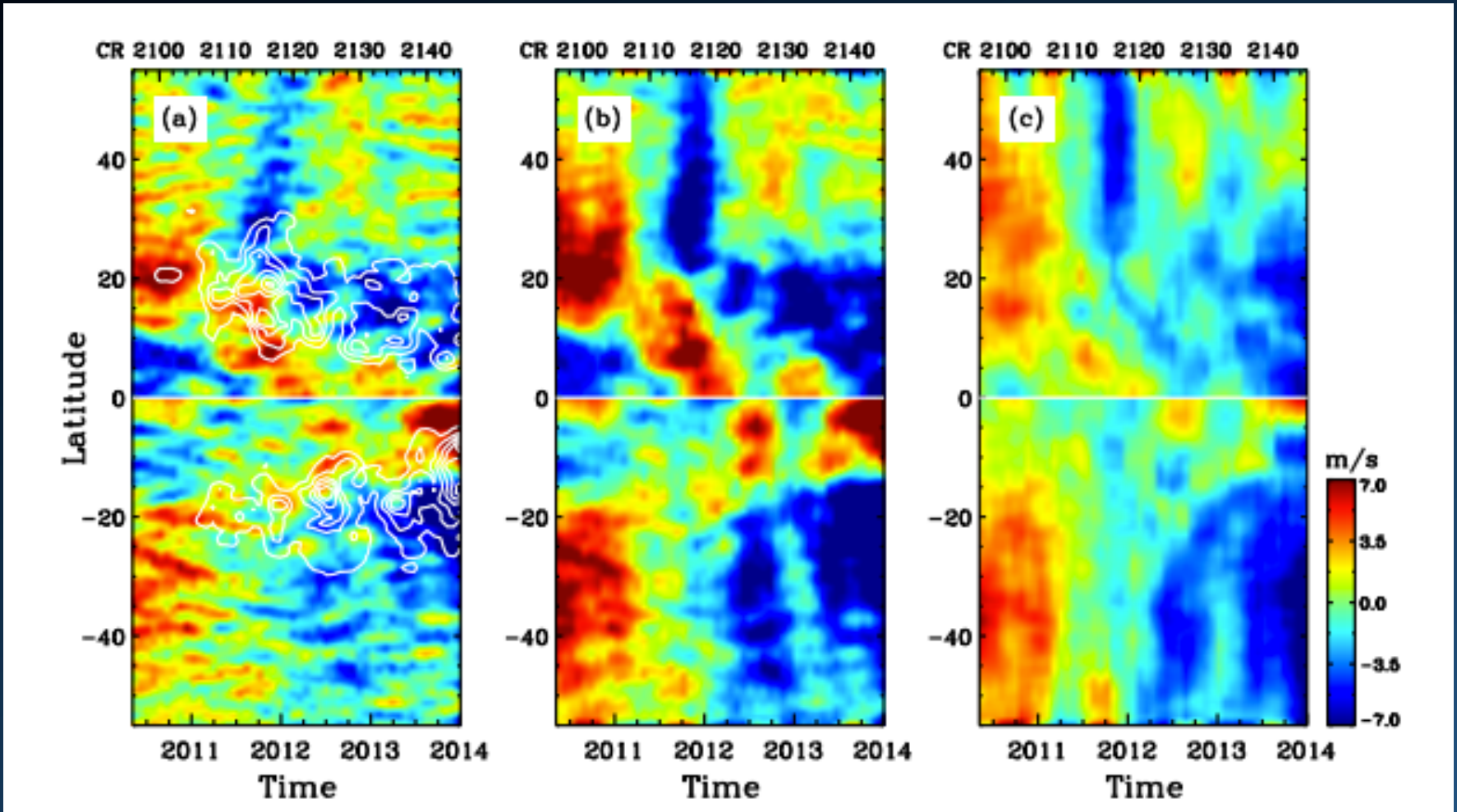
m/s

m/s

Gizon and Rempel, 2008, time-distance helioseismology

Meridional flow residual

(red = poleward)



0 to 1 Mm 3 to 5 Mm 10 to 13 Mm

Zhao, Kosovichev, & Bogart (2014), time-distance helioseismology

Part III: comparison with simulations

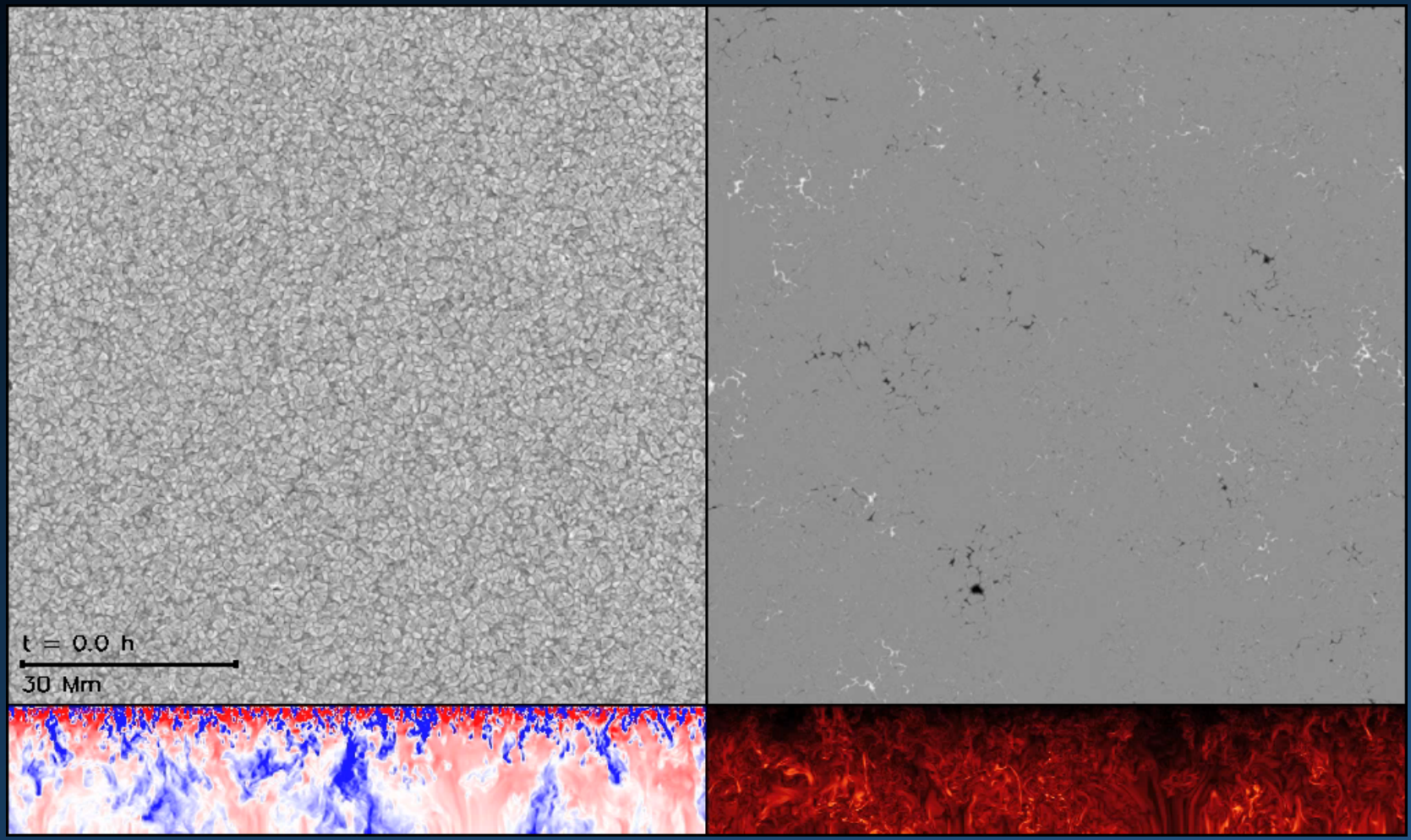
Motivations

- We see a tendency for converging flows before the emergence of AR
- What causes these flows?

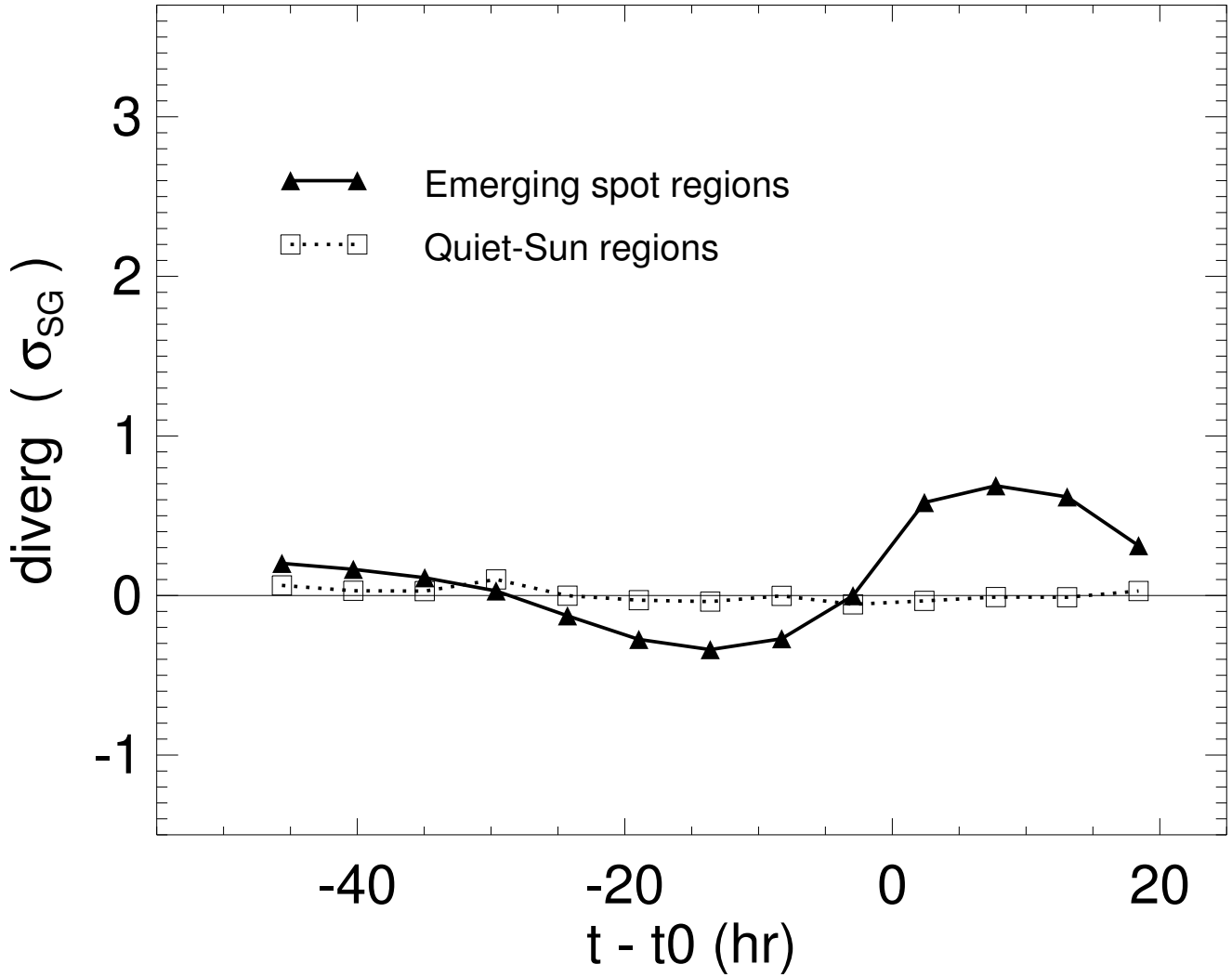
Setup of the simulations

- MURaM simulations (Cheung and Rempel, 2014, but with different parameters)
- Domain size 100 Mm x 100 Mm x 18 Mm
- Magnetic flux tube introduced through the bottom boundary (10^{22} or 0.5×10^{22} Mx)
- Choose emergence location and speed

Flux tube inserted in convective downflow; inflow speed 140 m/s
MURaM simulation (Cheung & Rempel, 2014)

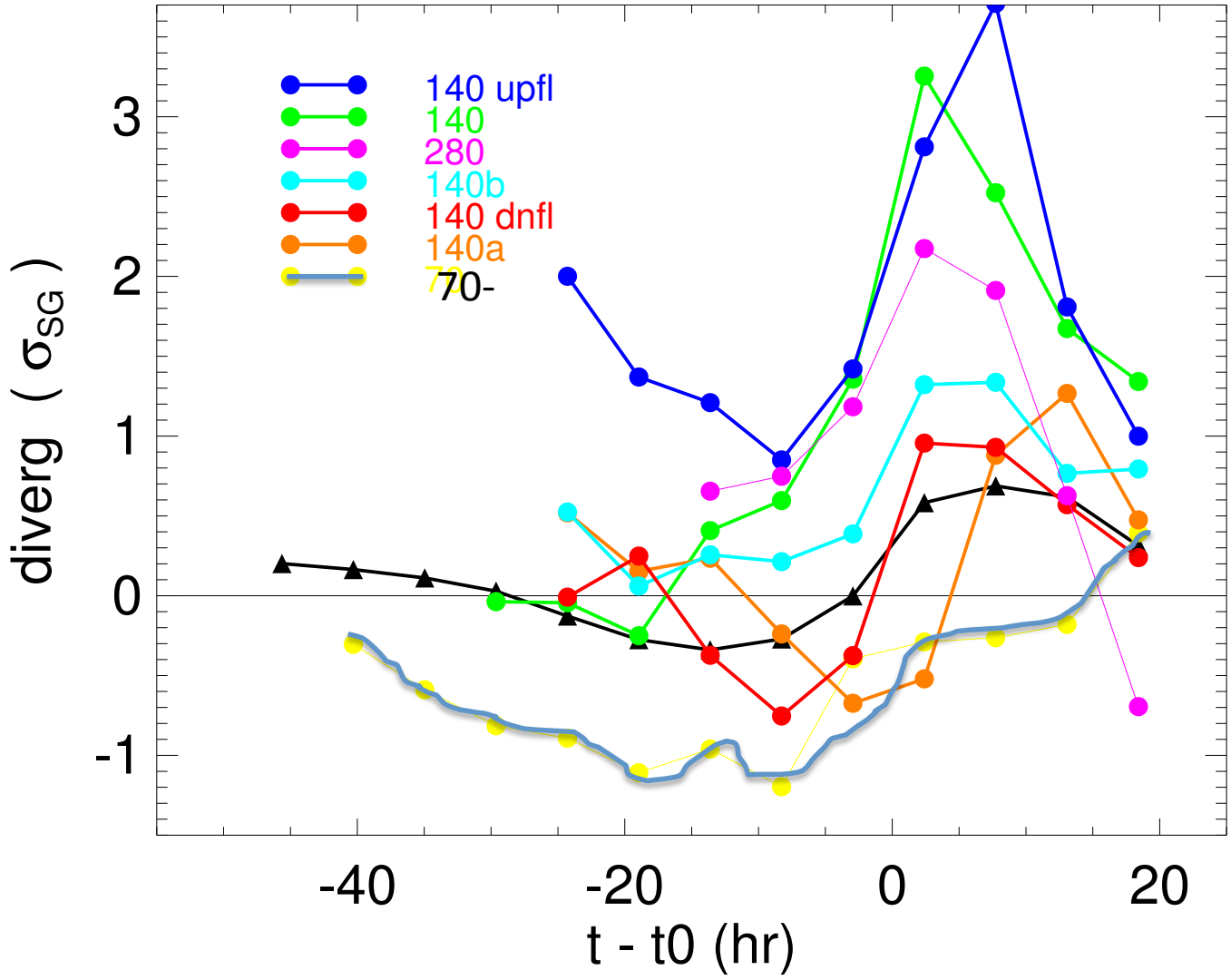


Reminder: converging flows before emergence



Simulations qualitatively like the observations

(except in cases when the upflow is too large)



Conclusions

- Observations:
  - Near-surface converging flows of about 50 m/s for about 30 hours before emergence
  - at time of emergence, flows switch from converging to diverging
- Simulations: flux tubes initiated with weak upflows show a similar pattern as the observations

- **I don't know why**

Thank you