Solar-Cycle Variation of Subsurface Flows derived from GONG and SDO/HMI

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Outline

- Introduction
- Zonal Flows
- Meridional Flows
- Summary

Introduction

- The zonal flow varies with the solar cycle (so-called torsional oscillation pattern). The poleward branch is less explored with local helioseismology.

- The meridional flow sets the timing of the solar cycle in flux-transport models. The meridional flow plays a role in the evolution of polar magnetic fields.

- Subsurface flows from ring-diagram analysis (0-16 Mm)
  GONG since July 2001; flows within 52.5º latitude.
  SDO/HMI since May 2010; flows up to 75º latitude.

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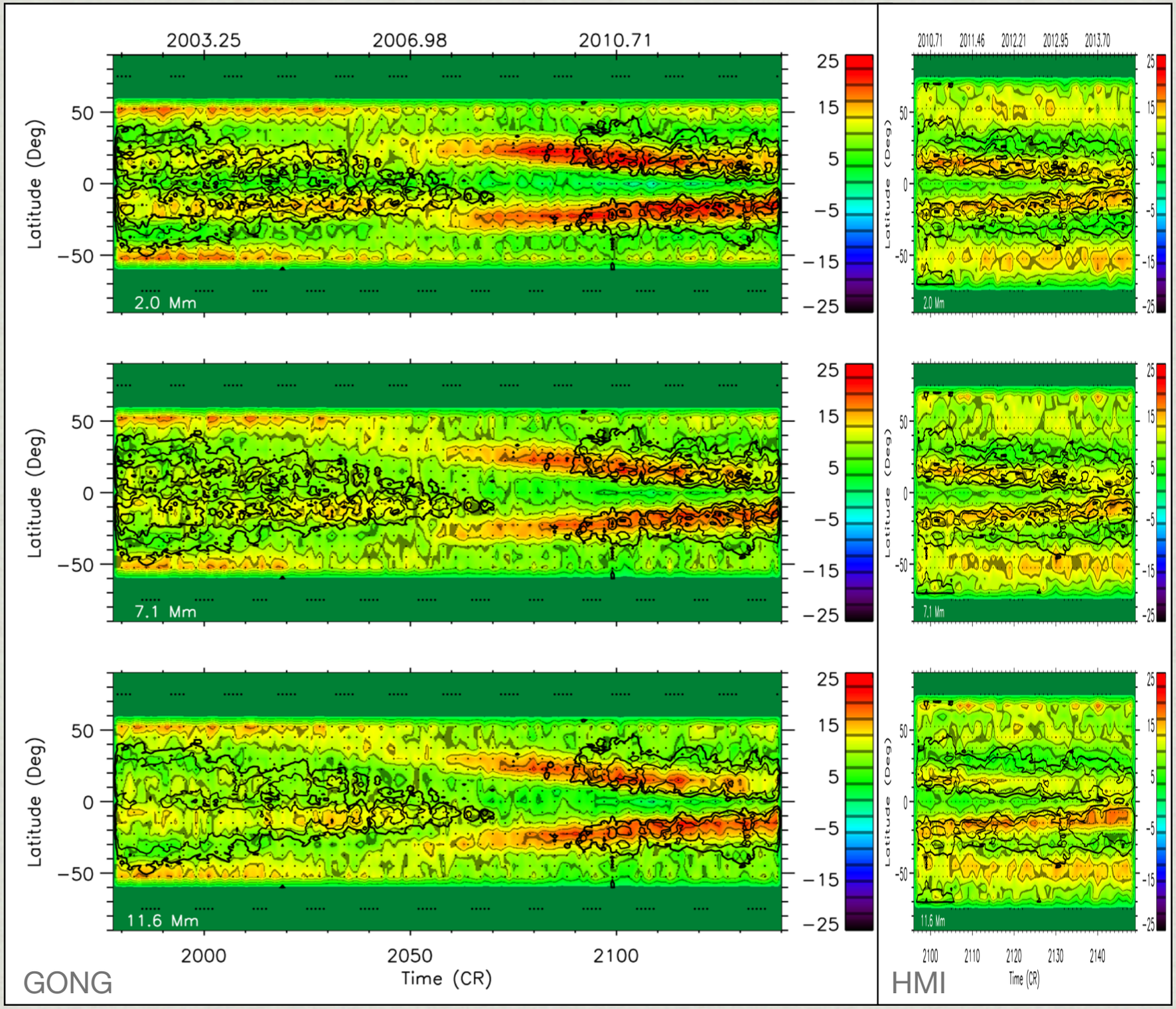
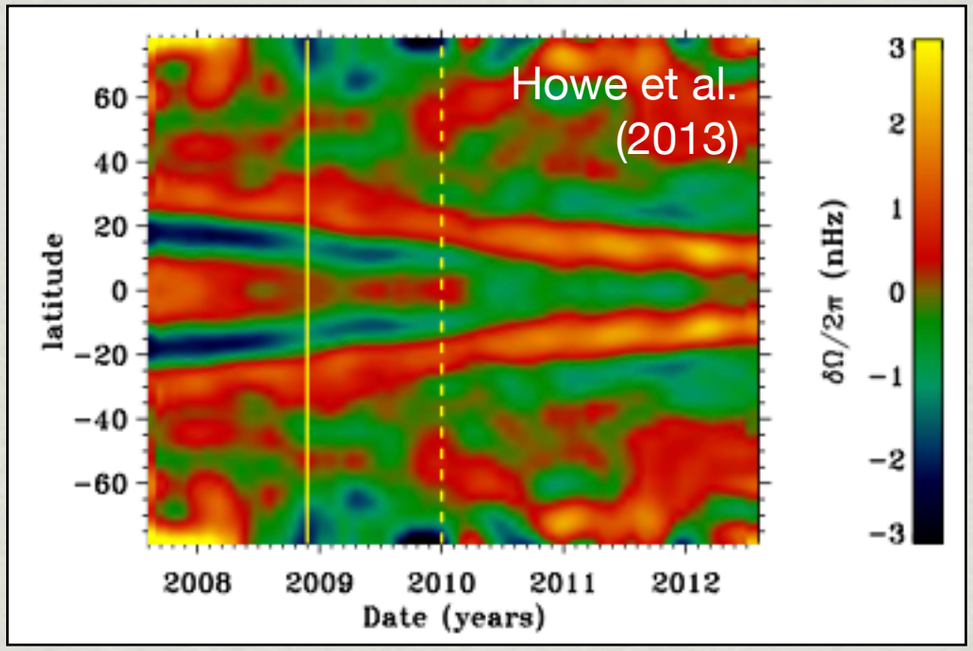
Solar-cycle variation

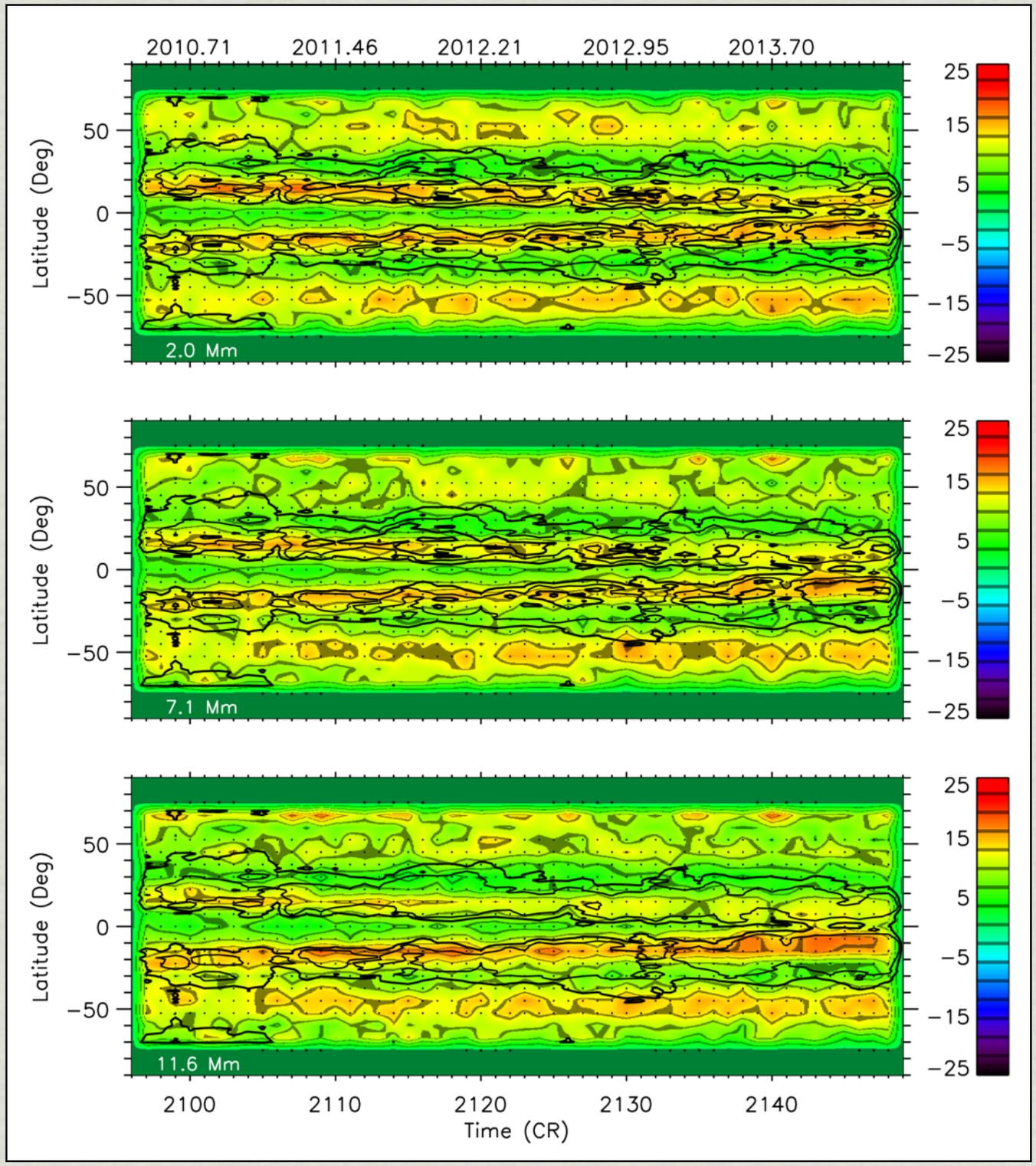


Bands of fast zonal flow occur near the equator during maximum and declining phase of cycle 23 and migrate from mid-latitudes to lower latitudes during minimum and beginning of cycle 24.

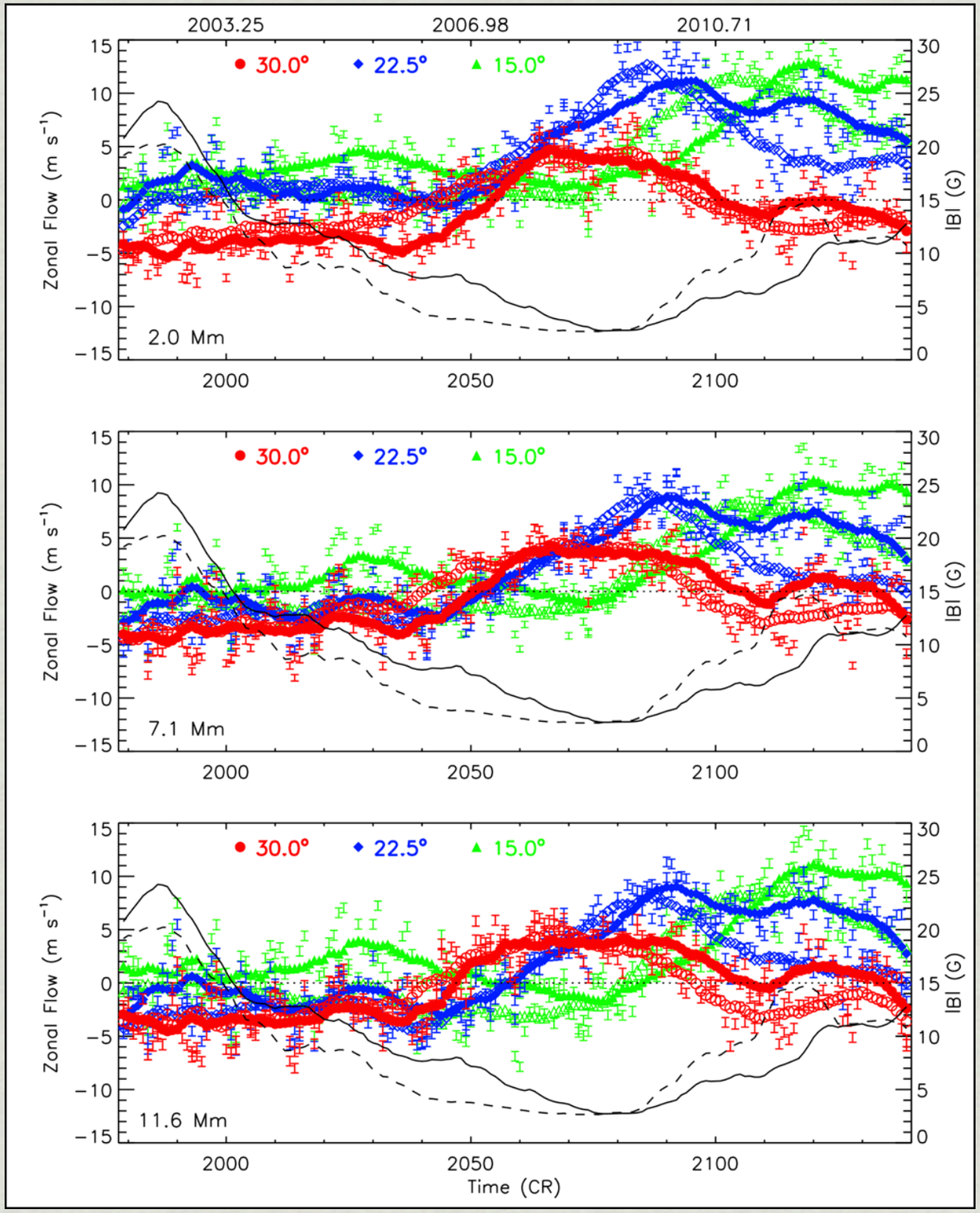
Poleward branch



Fast zonal flows are seen at 50° latitude in global results (top-left).
The poleward branch is visible in HMI ring-diagram data especially in the southern hemisphere.



Zonal flows at low latitude



The zonal flow begins to increase first in the northern hemisphere during cycle 24.
The magnetic activity does the same.

The increase in zonal flow occurs 3-4 years before magnetic activity increases.

South: filled symbols; solid line
North: open symbols; dashed line.

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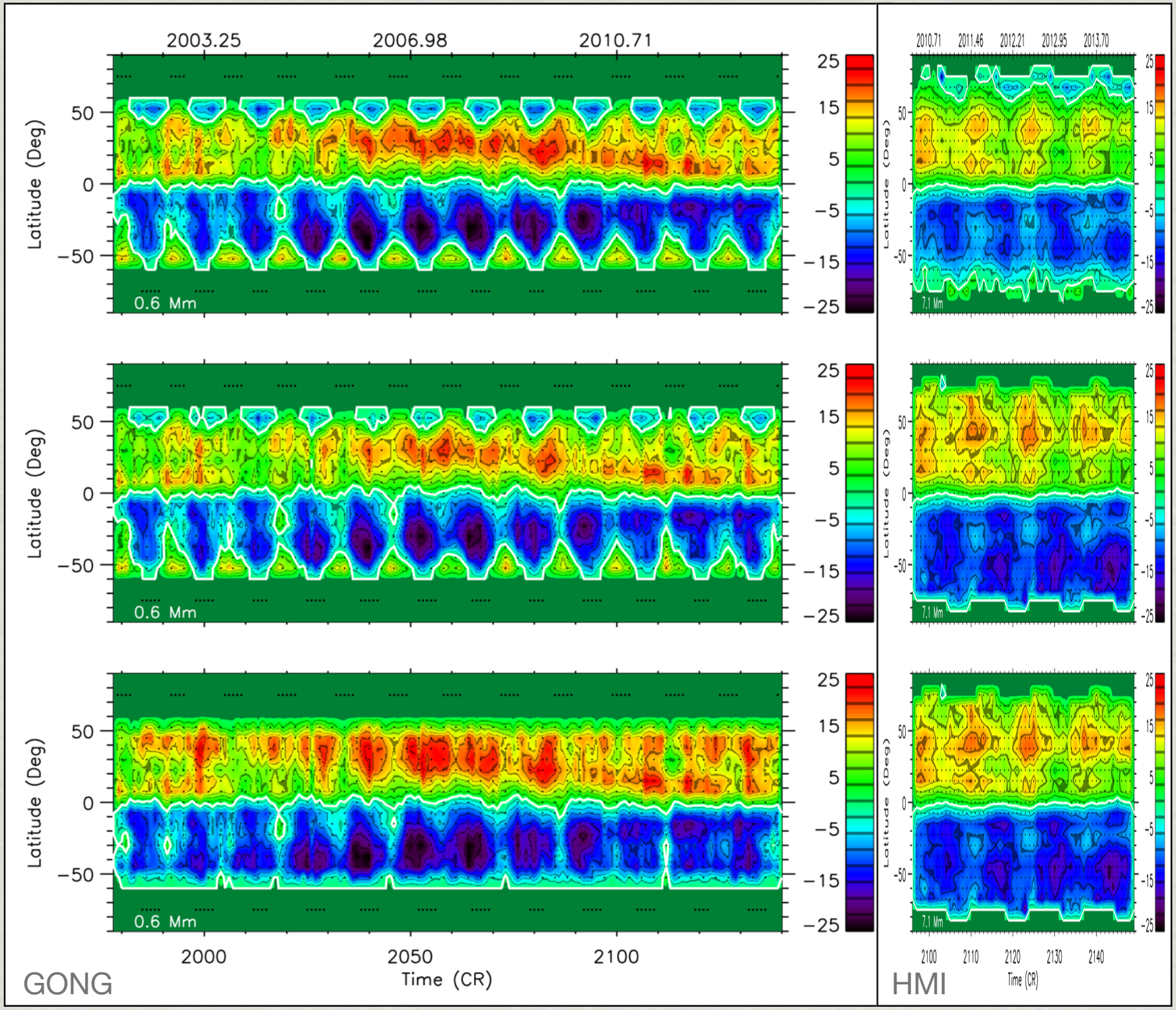
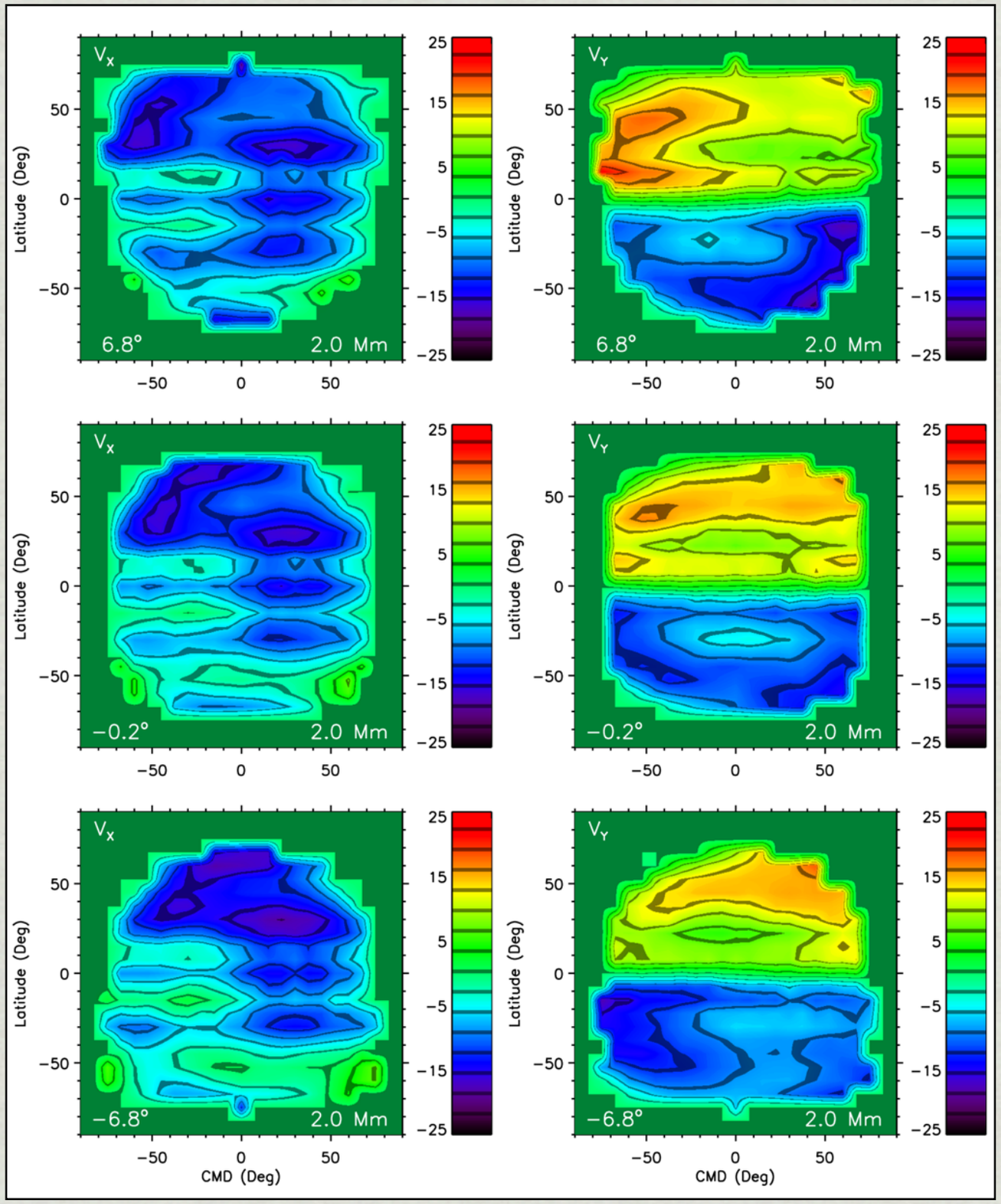
Variation with B_0



The meridional flow varies with B_0. The effect is smaller in HMI data (top). The variation is reduced in the flows corrected for E-W and N-S trends (middle) and absent from B_0-corrected flows (bottom).

Disk-averaged subsurface flows

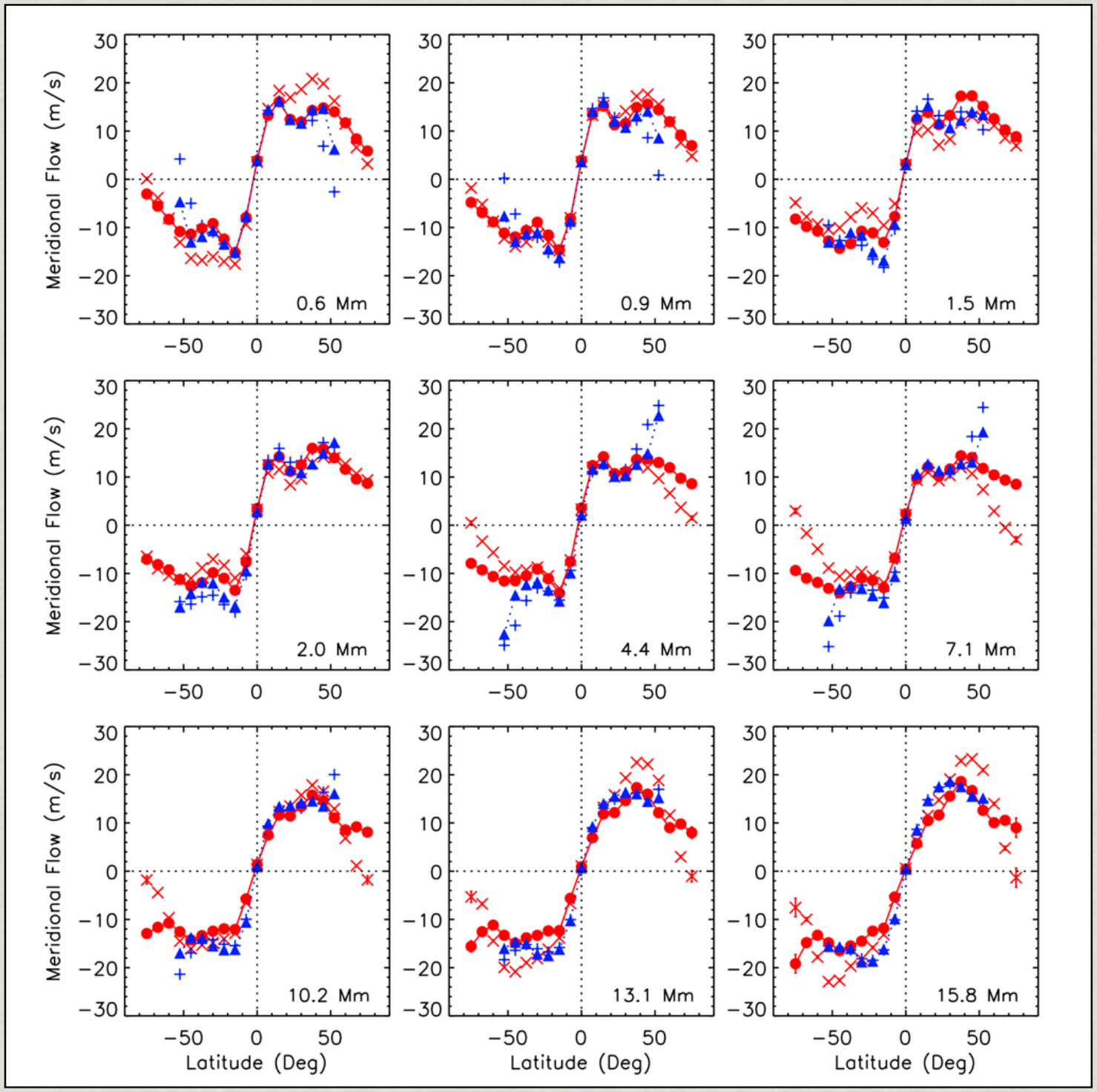


The systematic trends in East-West and North-South directions can be represented by radial velocity functions.

HMI CR 2097 - 2148
Left: zonal flow
Right: meridional flow.

Top: $B_0 > 6^o$
Middle: $B_0 \sim 0^o$
Bottom: $B_0 < -6^o$

Average meridional flow



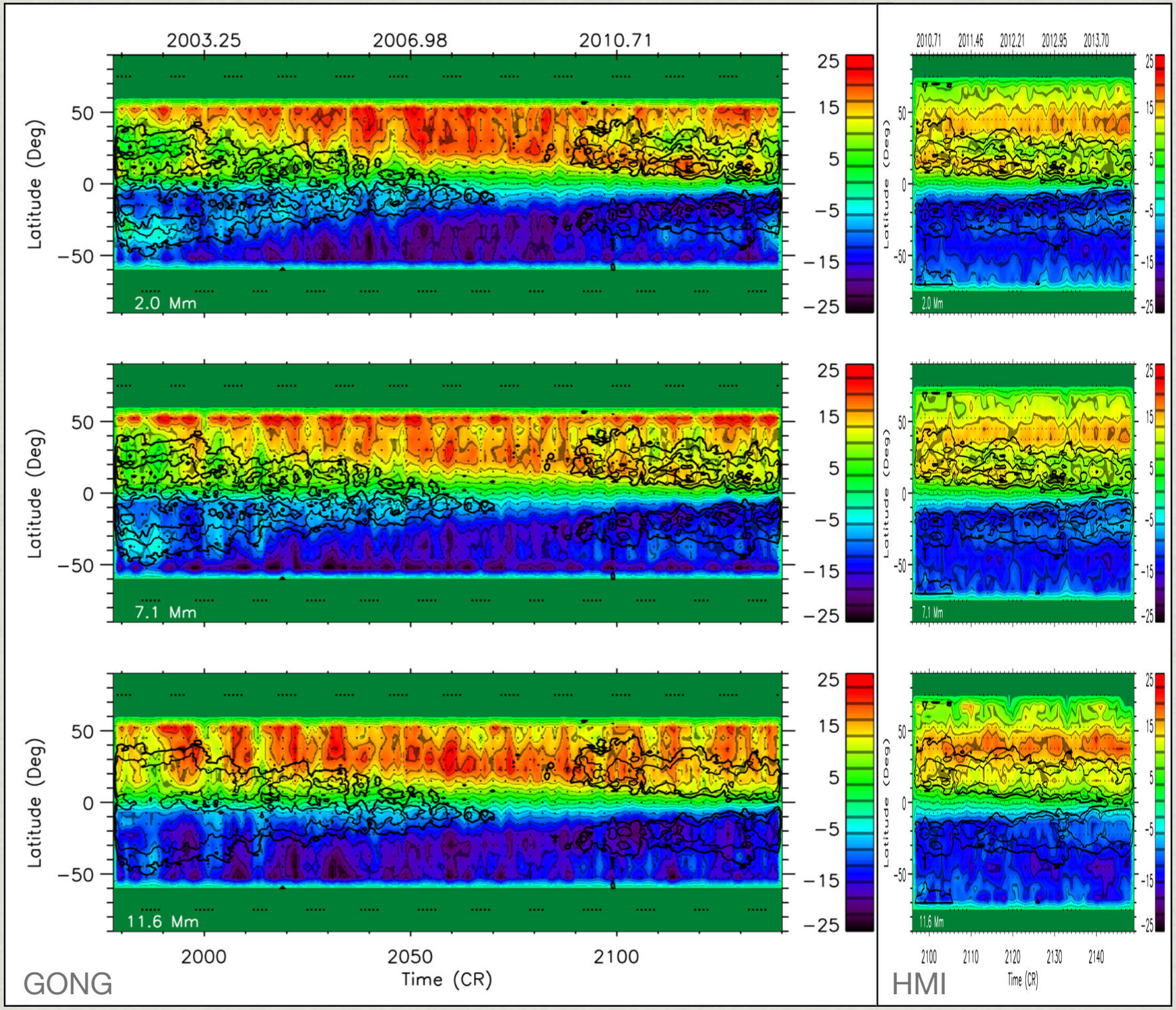
Corrected for E-W, N-S, and B_0 systematics.

CR 2097 - 2138
GONG (blue), HMI (red)

Corrected flows from HMI and GONG (●, ▲) are comparable.

No equatorward flows (counter cells) at high latitudes!

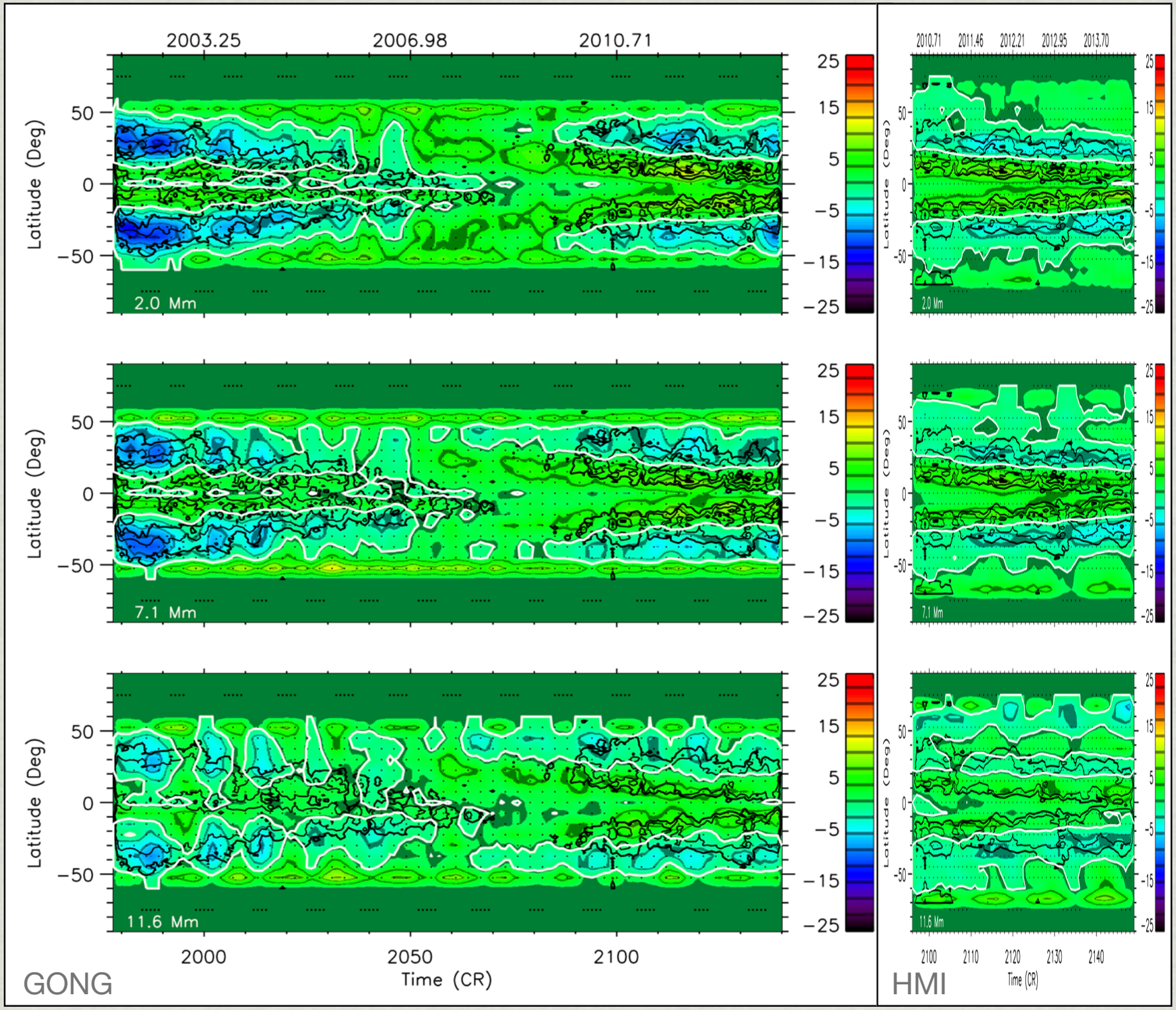
Solar-cycle variation



Flow amplitudes are small during maximum of cycle 23 and increase toward minimum.
Are they getting smaller again in cycle 24?

GONG and HMI lead to similar flows.

Residual meridional flow

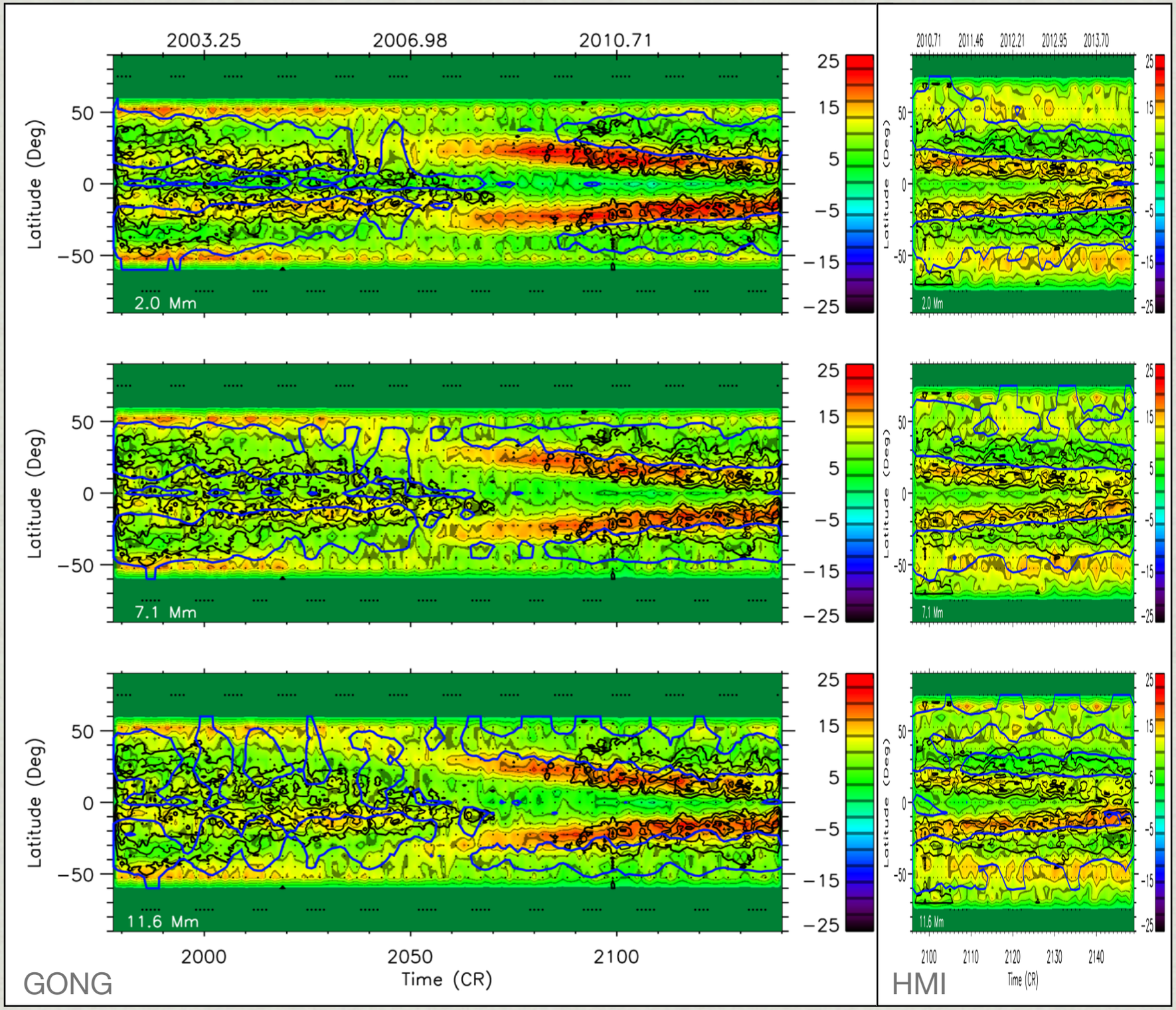


Residual flows converge near mean latitude of activity.

Pattern of cycle 24 starts in the north.
It was stronger in the south during previous maximum.

Positive is poleward; negative is equatorward.

Residual zonal & meridional flow



Poleward residual meridional flow coincides with fast zonal flow.

Equatorward residual meridional flow coincides with slow zonal flow.

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Summary

- The zonal flow shows bands of faster-than-average flows migrating from mid- to low latitudes.
- The poleward branch of the solar-cycle pattern in zonal flows is visible in HMI and GONG ring-diagram data.
- The rotation rate has slowed down at high latitudes after the maximum of cycle 23.
- Precursor of magnetic activity: the zonal flow increases about 3-4 years before magnetic activity increases during cycle 24.

Summary

- The amplitudes of the meridional flow are large during cycle minimum and small during cycle maximum.
- No equatorward meridional flow at latitudes up to 75°.
- The residual meridional flow shows bands of converging flow migrating from mid- to low latitudes.
- The poleward residual meridional flow coincides with the fast band of the zonal flow.
- The equatorward residual meridional flow coincides with the slow zonal flow between the two branches of the torsional oscillation.