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TAKING THE PULSE OF OUR PLANET FROM SPACE

Core surface flow changes associated with the 2017 Pacific geomagnetic jerk

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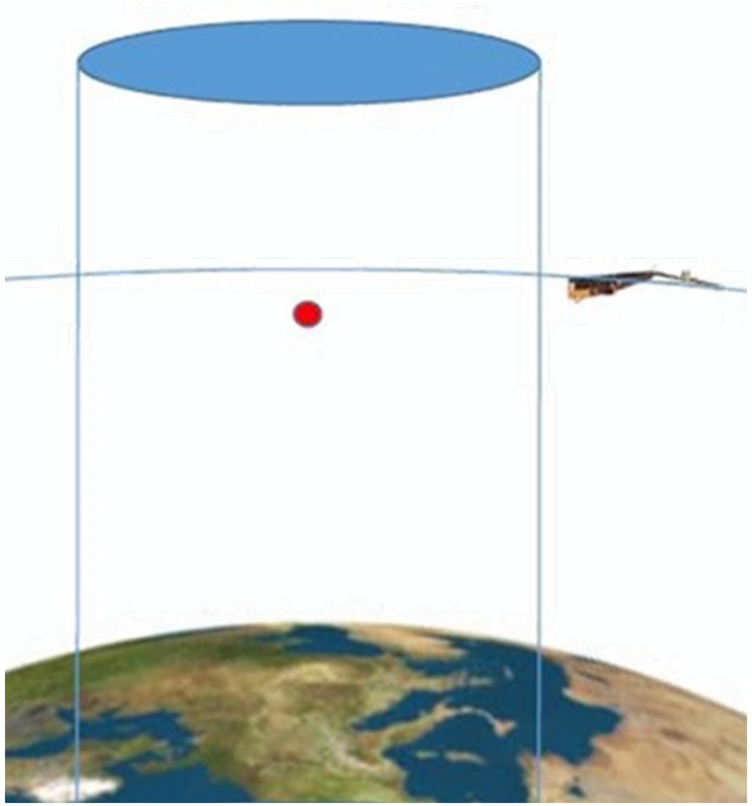
Outline

- Geomagnetic Virtual Observatory (GVO) spatial gradients dataset
- Advective flow inversion over Swarm epoch
- Flow changes associated with the Pacific 2017 jerk
- Summary

Geomagnetic Virtual Observatories (GVOs)

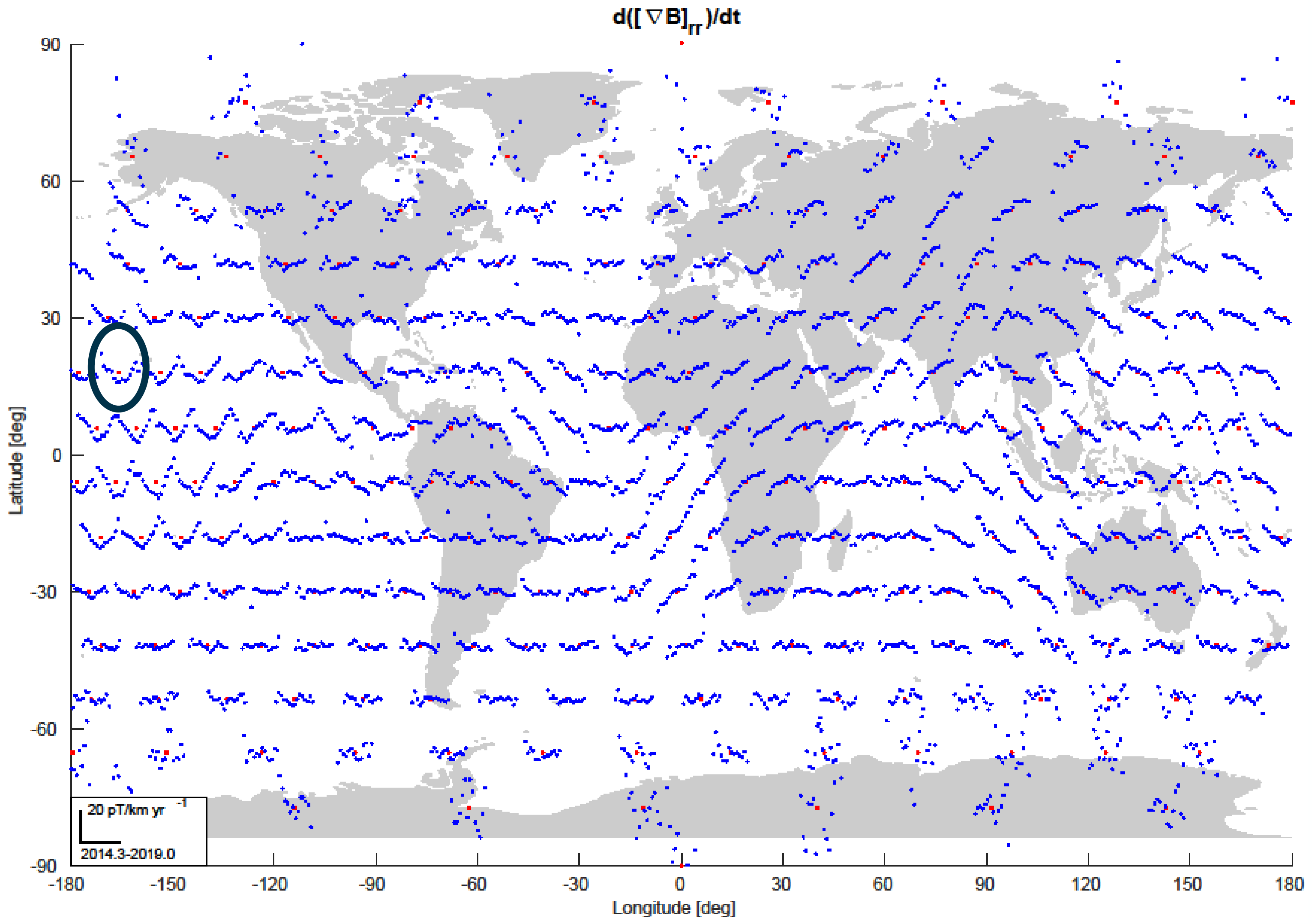
- Select data within a cylinder, radius 700 km, passing through the GVO (red dot)
- 300 GVOs roughly equally distributed
- Various data selection criteria and corrections
- Data represented by a cubic local potential field
- Reduce large amounts of satellite data to time series of values at a single point, the GVO
- 4-month interval between epochs to get good coverage of GVO volumes



GVOs (continued)

- *Swarm* along- and (for alpha and charlie) across-track sums and differences to obtain spatial gradients
- Symmetric around the diagonal
- 6 spatial gradient tensor elements, 5 independent (trace vanishes)
- SV estimates from annual first differences
- Used GVO data from 2014 to 2019, 17 (4-monthly) epochs

Example of VO SV gradient time series



Time series over the Swarm era of $\nabla \dot{B}_{rr}$ at GVO locations, shown by red dots

Black ellipse is GVO for which the flow predictions are shown later

Pacific region rapid changes seen in SV vector as well as gradient data

Flow inversion method

- Assume magnetic field frozen-in to fluid at core-mantle boundary (CMB) – magnetic diffusion negligible
- Magnetic field, $\mathbf{B}$, its rate of change, $\dot{\mathbf{B}}$, and flow, $\mathbf{v}$, related by diffusionless induction equation
- Expand in spherical harmonics and treat as an inverse problem for coefficients of $\mathbf{v} = (0, v_\theta, v_\varphi)$, with data spatial gradients of $\dot{\mathbf{B}}$ from GVOs
- Assume main field perfectly known – specified by CHAOS
- Apply spatial and temporal regularisation

Regularisation

Used three spatial regularisations, minimising:

- 'Strong norm' (Bloxham, 1989), severely restricting strength of small-scale flow
- Kinetic energy of flow (Whaler, 1986)
- Root-mean-square (rms) CMB SV generated by flow advection (Whaler, 1986)

Temporal – minimise difference between flow at successive epochs (Whaler et al., 2016)

Hence invert for flow coefficients at all epochs simultaneously, but matrix relating flow coefficients to data is sparse

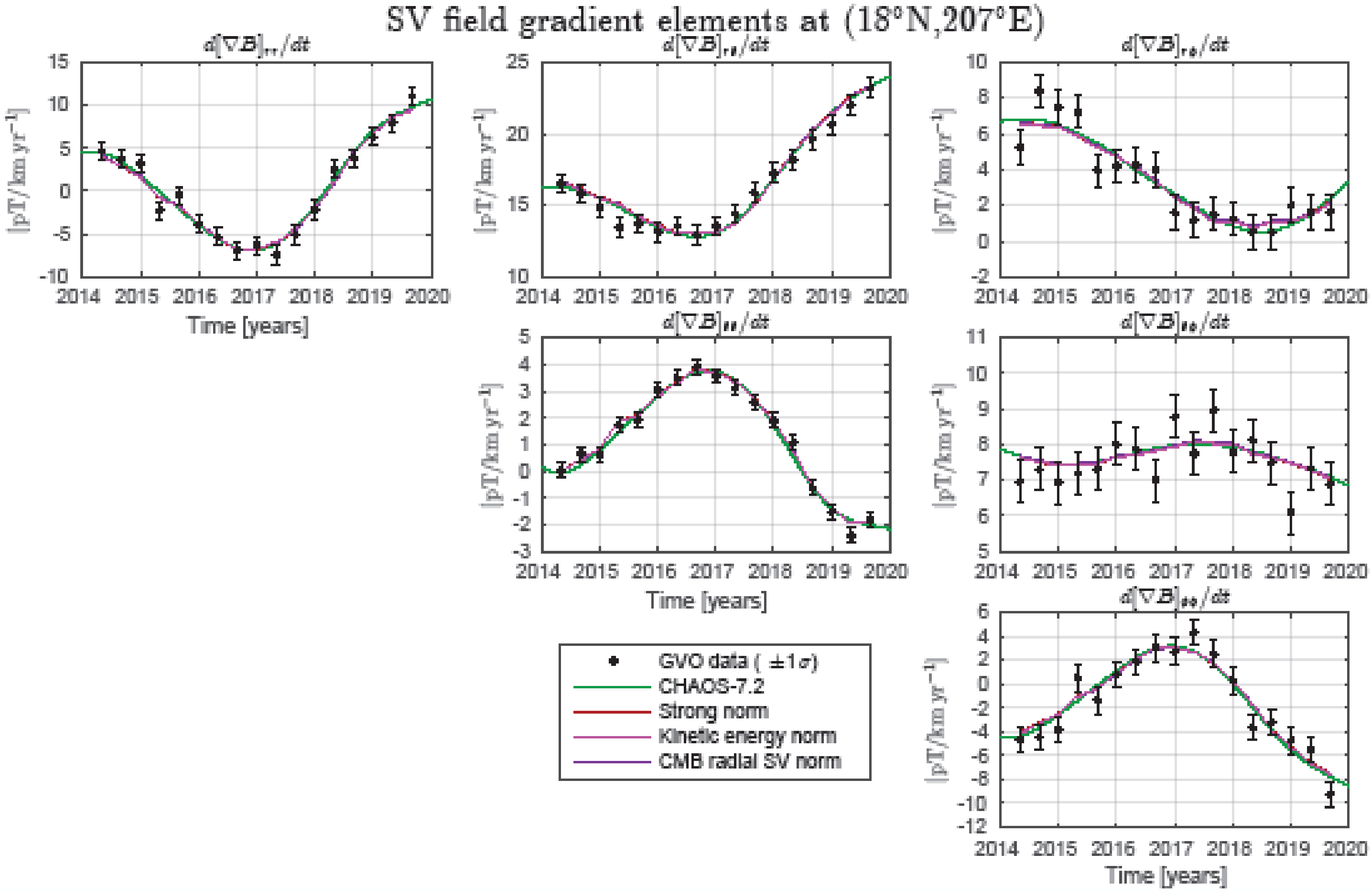
Solve for flow using Jacobi-preconditioned conjugate gradient method

Regularisation parameters control temporal and spatial 'smoothness' versus data fit

Results

- Find models with same rms data fit with different spatial regularisations (temporal regularisation fixed)
- SV gradients more sensitive to the flow than SV vector data: trace of resolution matrix (i.e. number of coefficients resolved) 150 for SV gradients compared to 100 for vector data
- Features of the data, including rapid changes, reproduced at least as well as by CHAOS

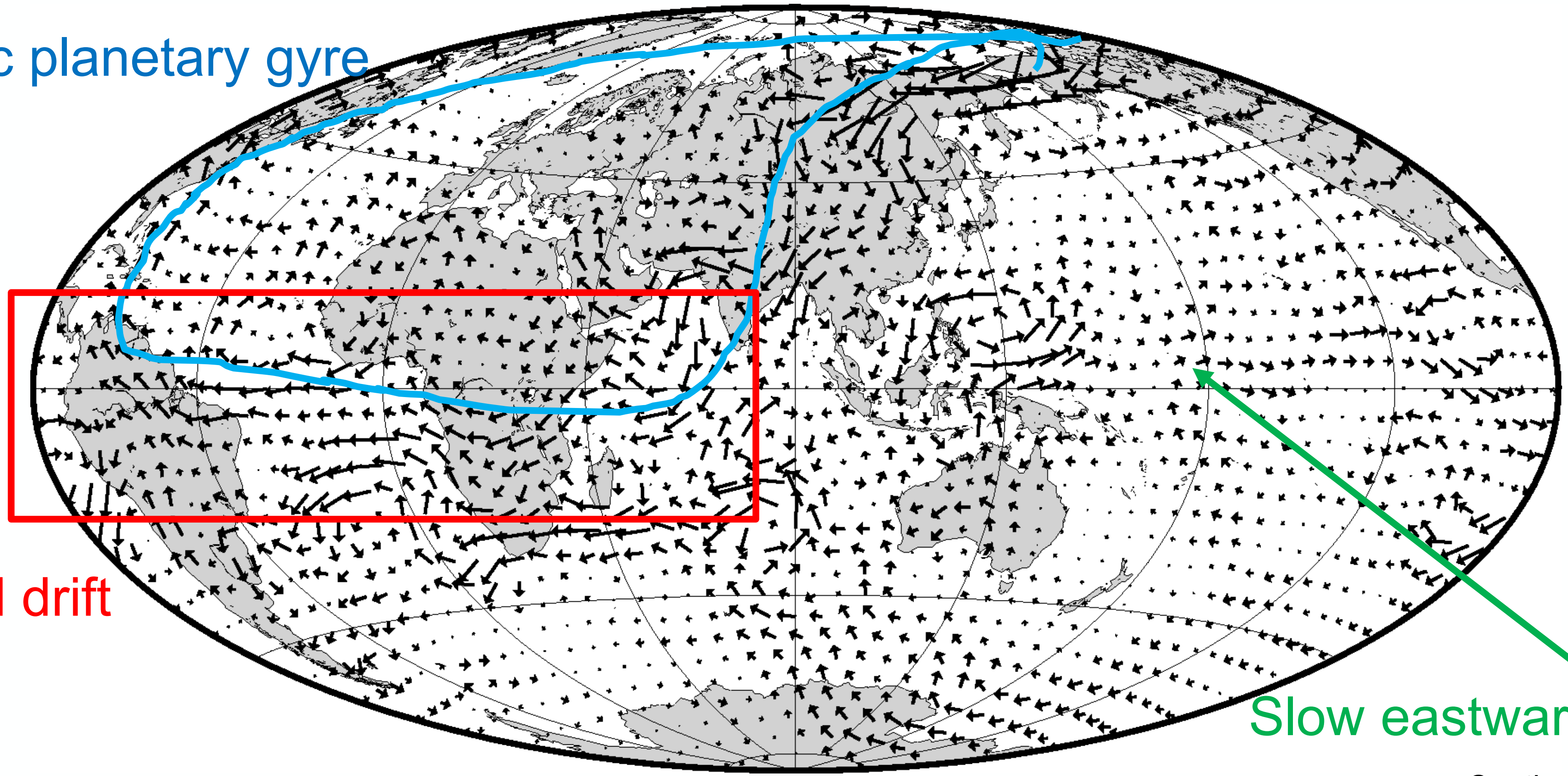
Data time series and their predictions by flows



Results (continued)

- Although the different spatial regularisations lead to rather different flow strengths and patterns, some general features of flows in previous studies can be identified:
  - Band of westward equatorial flow beneath the hemisphere centred on 0° longitude
  - Eccentric planetary gyre
  - Slower eastward flow beneath the Pacific hemisphere

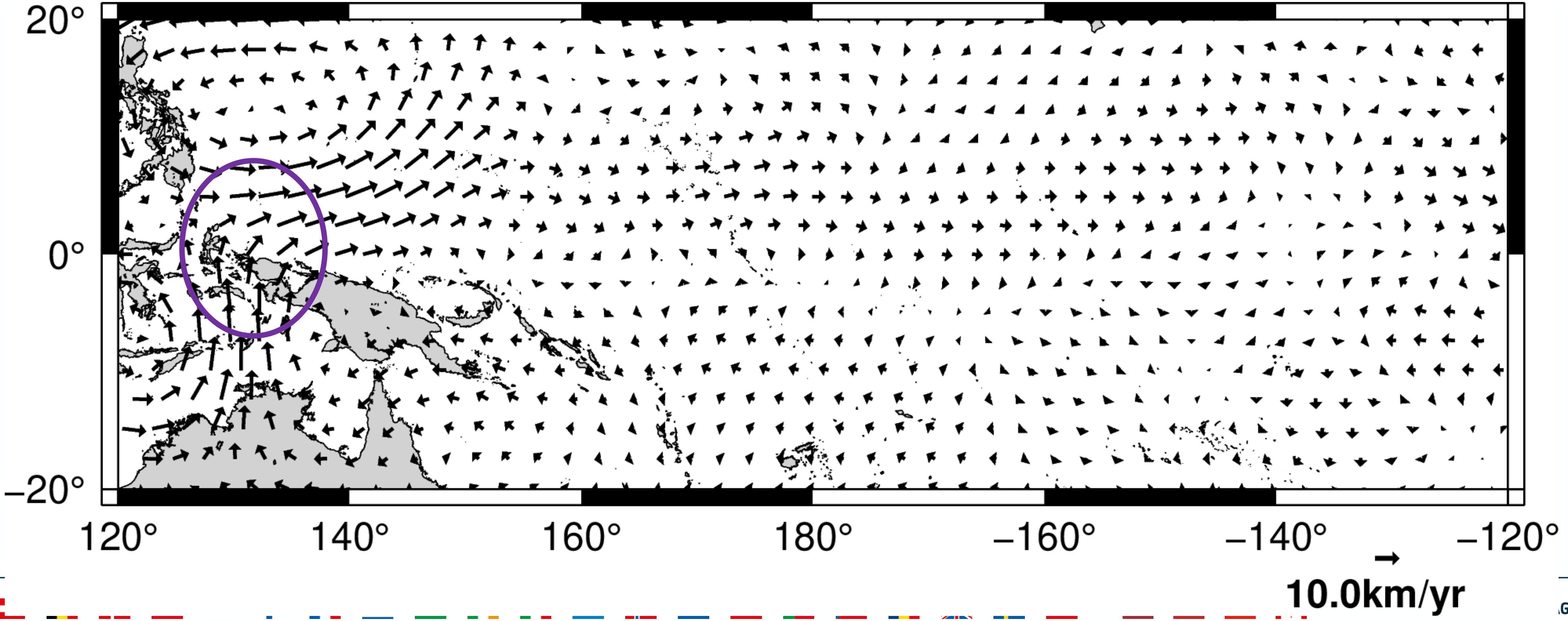
Example global flow



Continents for reference

Results (continued)

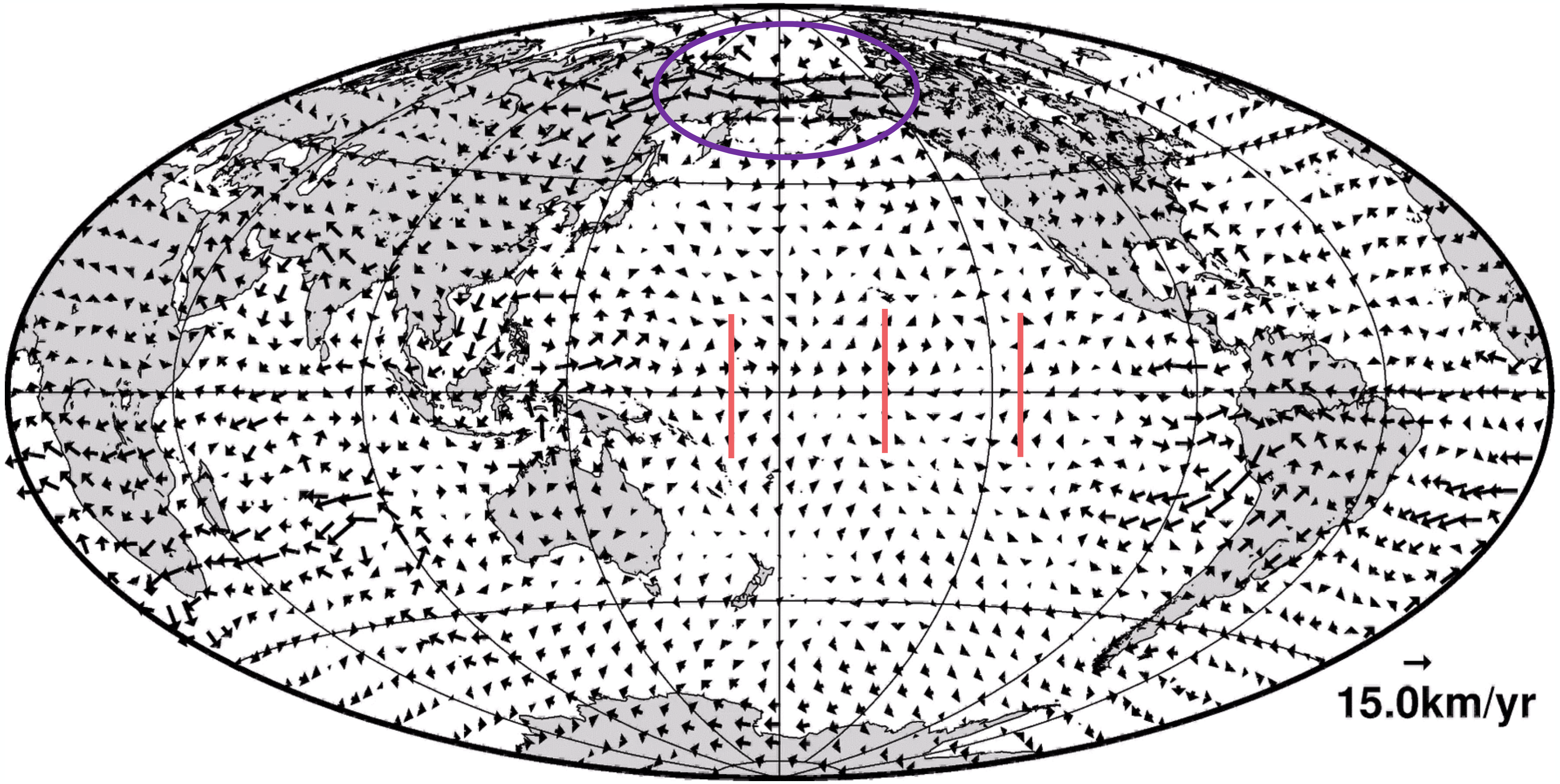
Beneath the Pacific, flows are non-equatorially symmetric and non-tangentially geostrophic, notably cross-equator flow below Indonesia (first noted by Bloxham (1989) in flows for 1975-80)



Results (continued)

Very little change in flow is required to satisfy the data

Small speed increase of jet along tangent cylinder beneath Alaska-Siberia identified by Livermore et al (2016)? (their speed tripled to 40 km/yr between 2000 and 2016)



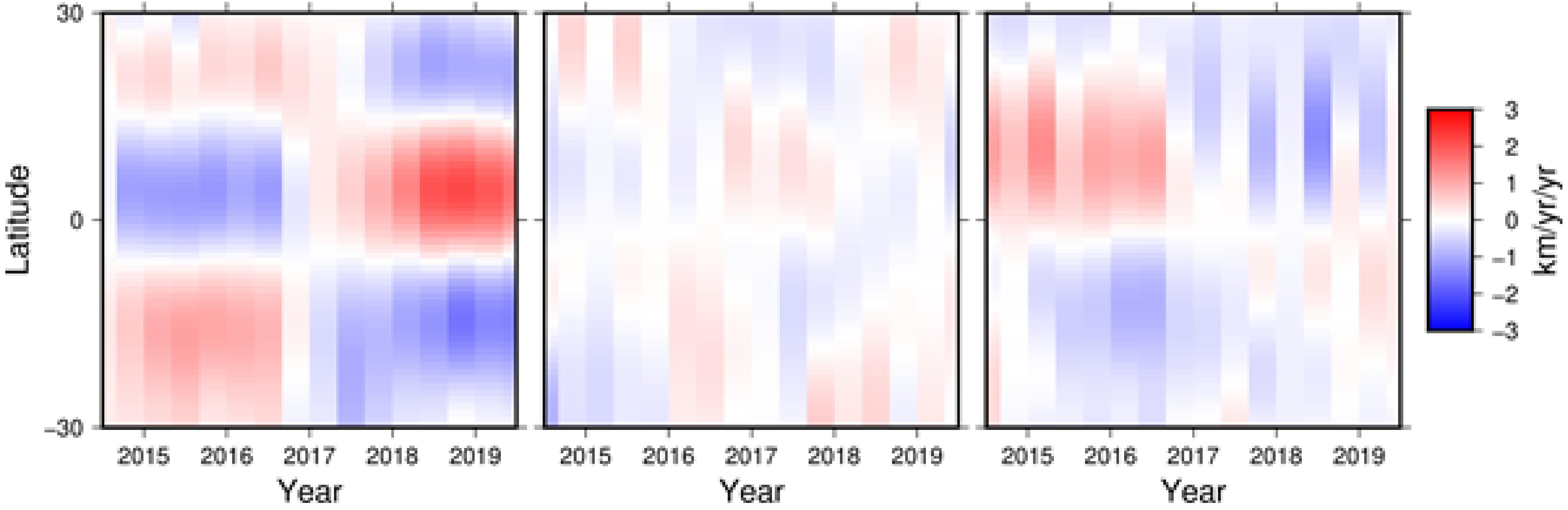
Results (continued)

Although flows depend on spatial regularisation, flow *changes* associated with the Pacific 2017 jerk are sudden and robust

Most clearly seen in ϕ-component of acceleration, calculated as simple first difference of flow, no smoothing:

- has the opposite sense either side of ~160°W
- acceleration very small at ~160°W
- changes sign at the jerk epoch

ϕ-component of acceleration



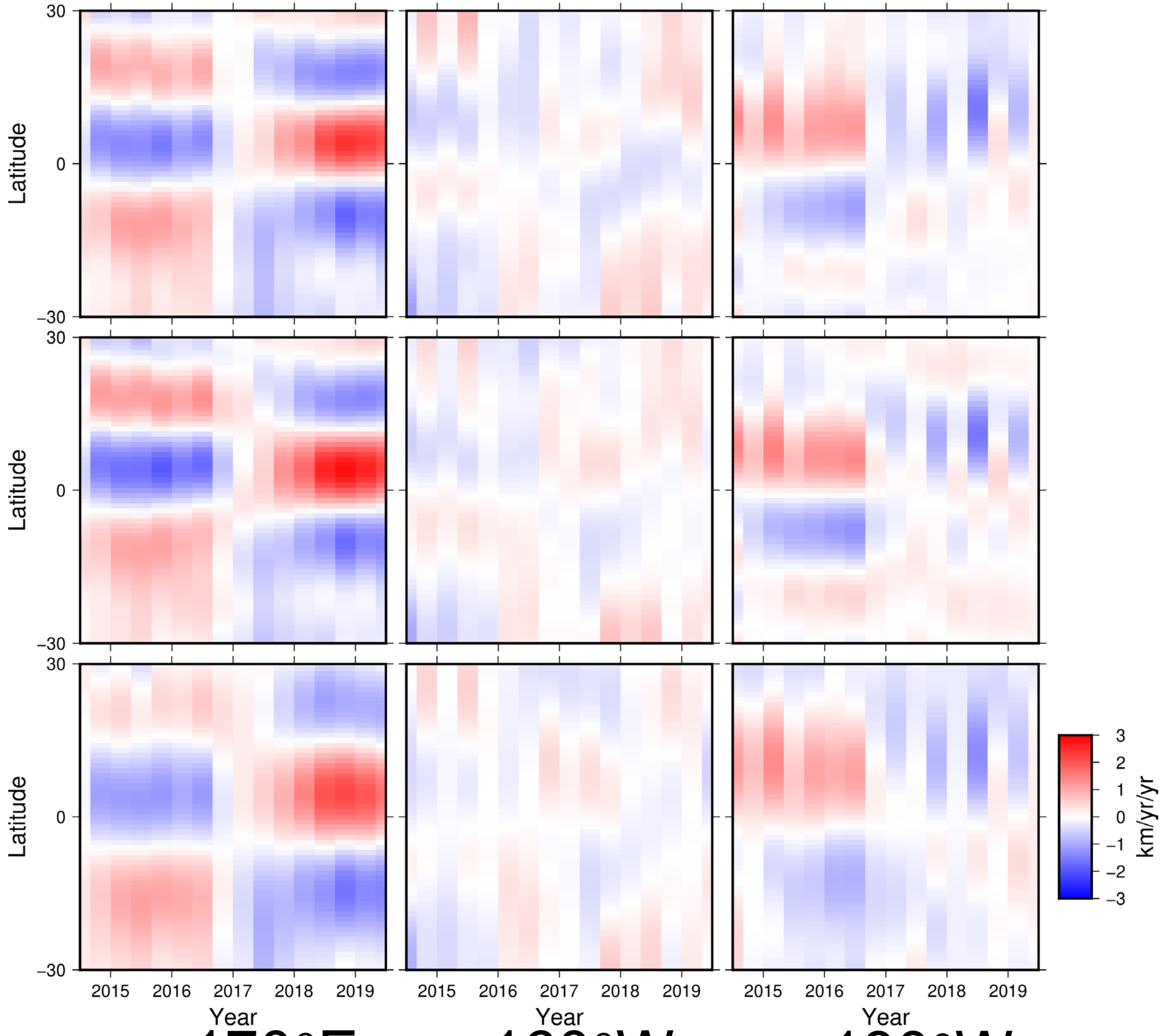
170°E

160°W

130°W

Strong norm

ϕ-component of acceleration



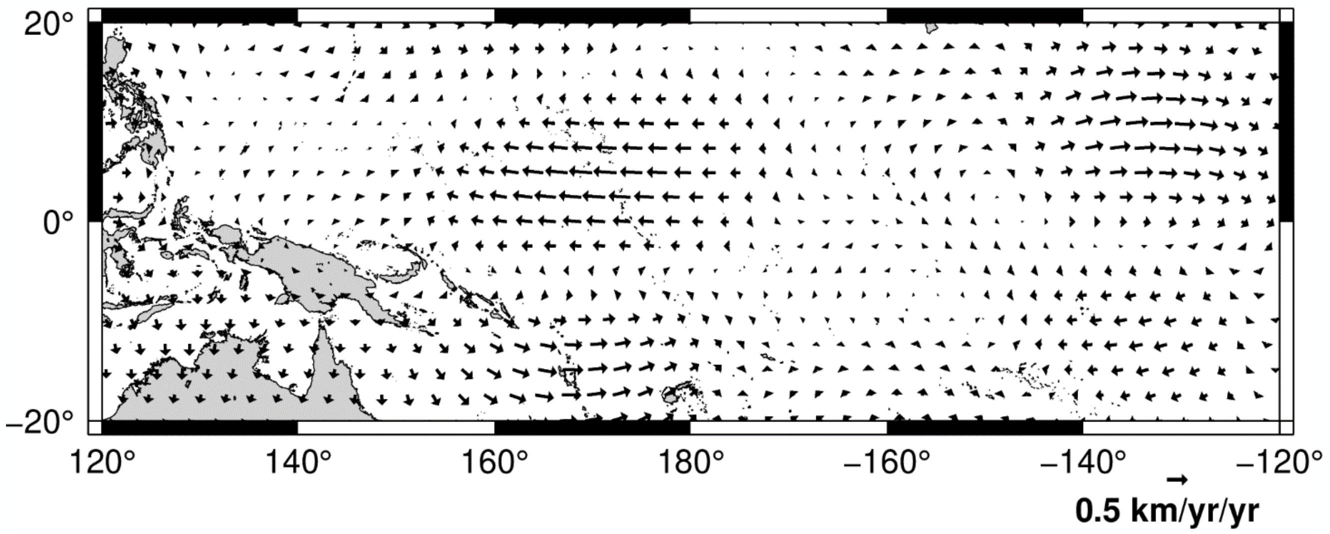
170°E 160°W 130°W

Minimum $\oint_{CMB} \dot{B}_r^2 d\Omega$

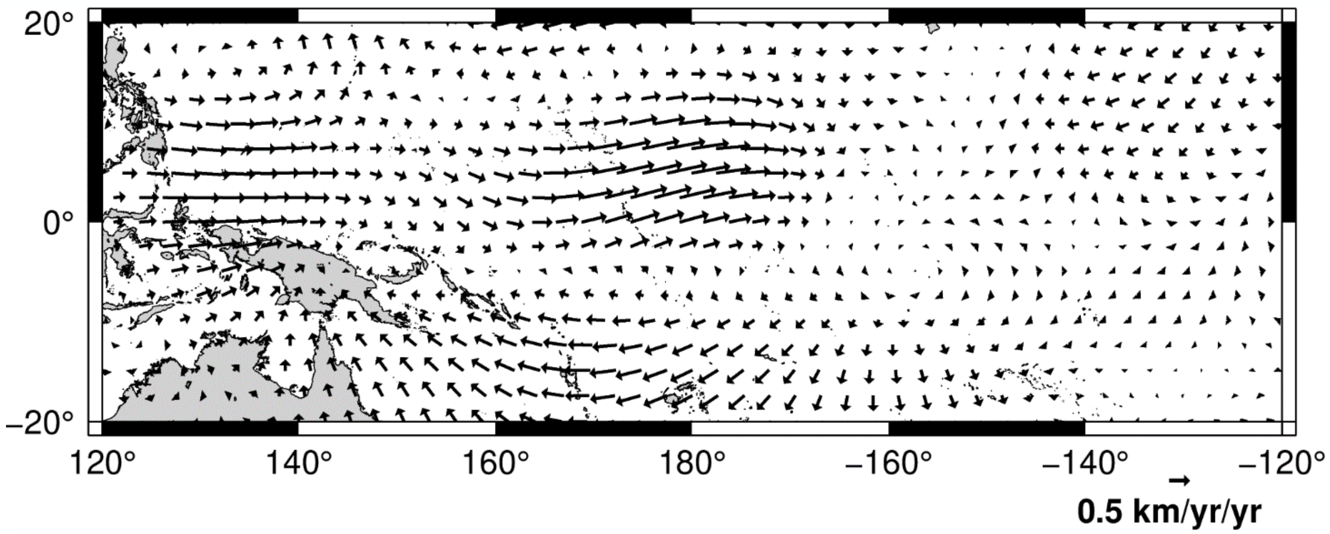
Minimum kinetic energy

Strong norm

Average acceleration before and after the jerk



Before

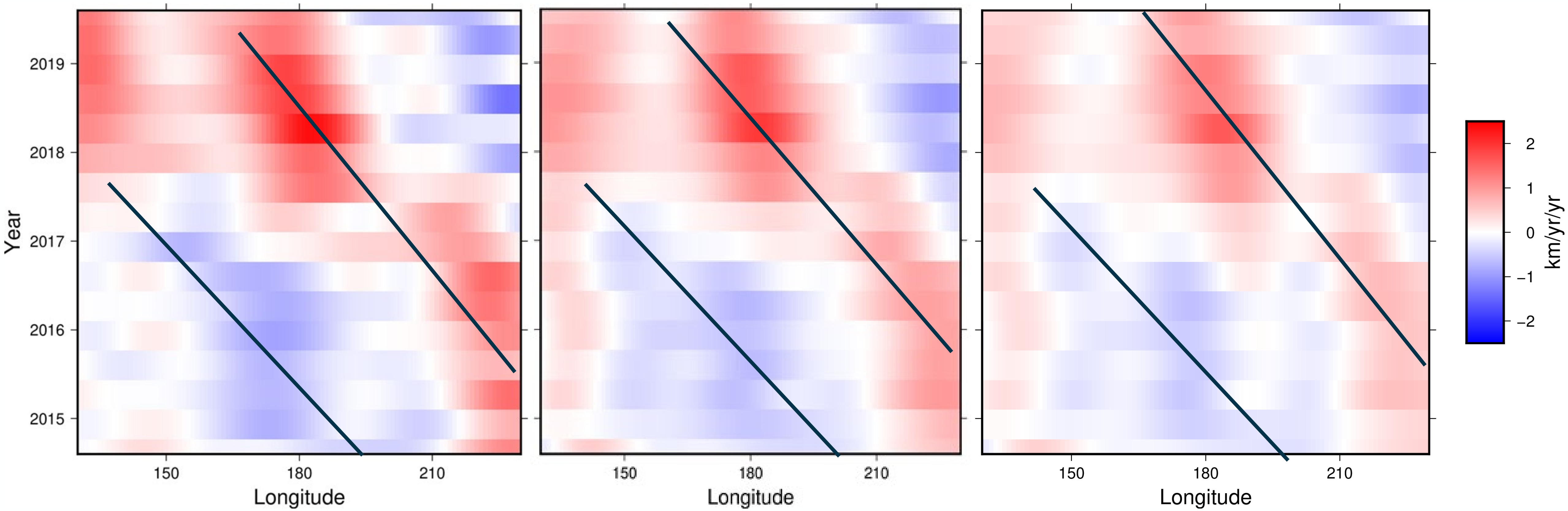


After

Strong norm

Suggestion of waves?

ϕ-component of acceleration at 10°N



Strong norm

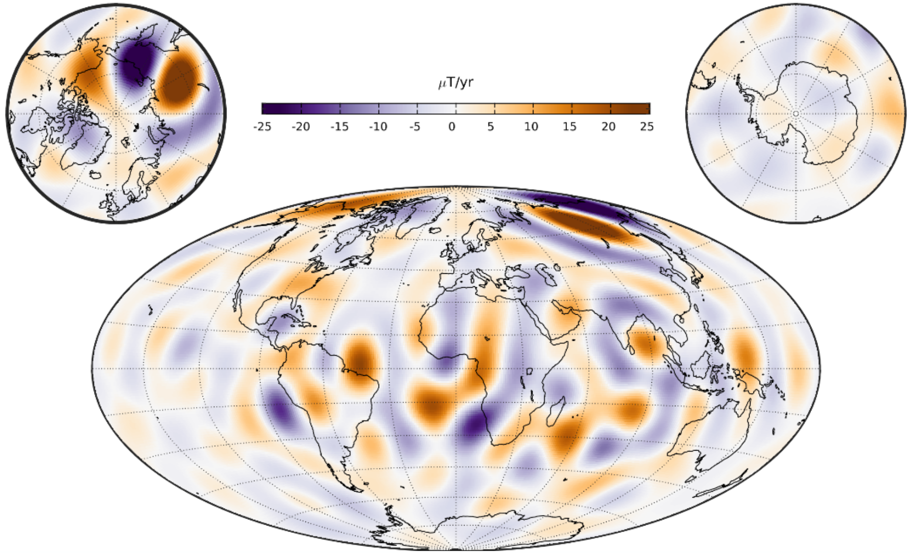
Minimum kinetic energy

Minimum $\oint_{CMB} \dot{B}_r^2 \, d\Omega$

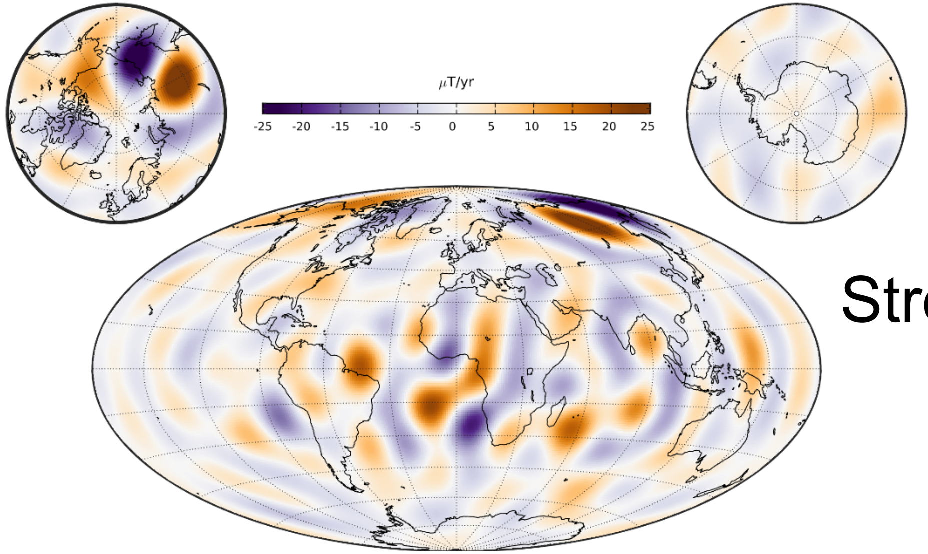
Summary

- SV gradient tensor data provide better resolution – more flow detail – than SV vector data for CMB advective flow
- Very modest flow changes are needed to reproduce rapid changes in SV vector and SV gradient data in the Pacific in 2017
- Flow details are dependent on choice of spatial norm
- However, accelerations are robust to spatial norm
- Distinctive pattern of rapid (spatially and temporally) acceleration change associated with 2017 Pacific jerk
- Exemplified by ϕ-component
- Tentative evidence for waves propagating at ~900 km/yr

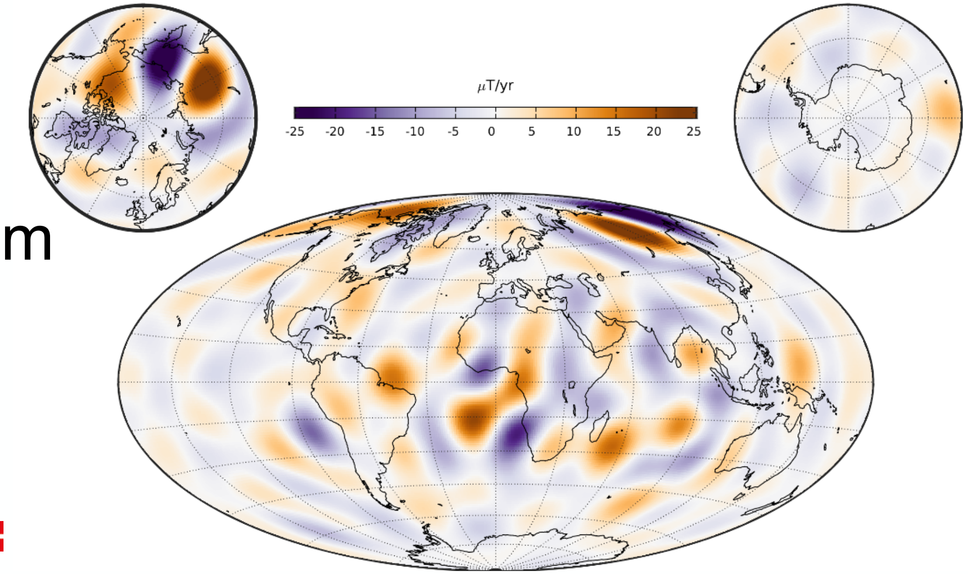
Core radial SV



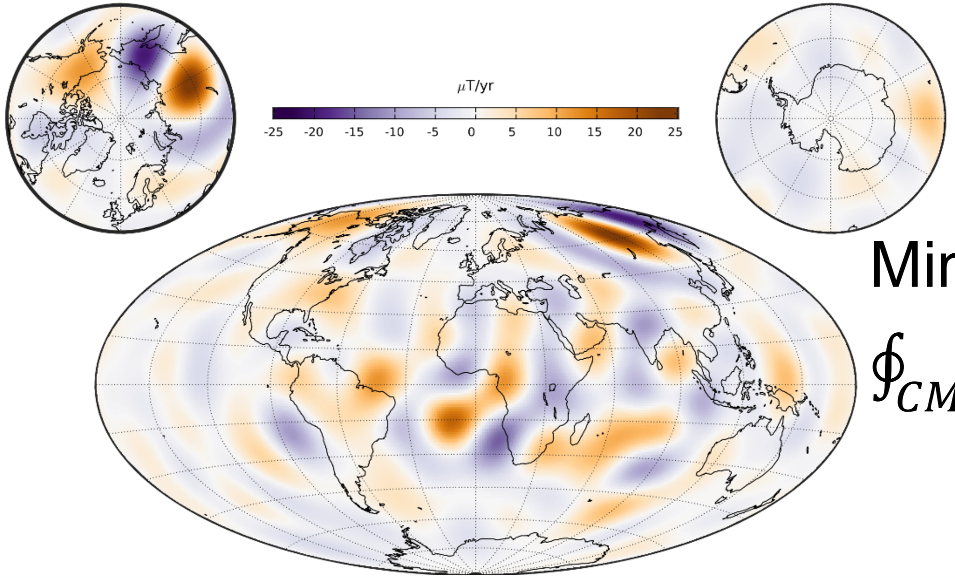
CHAOS



Strong norm



Minimum kinetic energy



Minimum $\oint_{CMB} \dot{B}_r^2 \, d\Omega$