Modeling toroidal currents in the ionospheric electrojet regions

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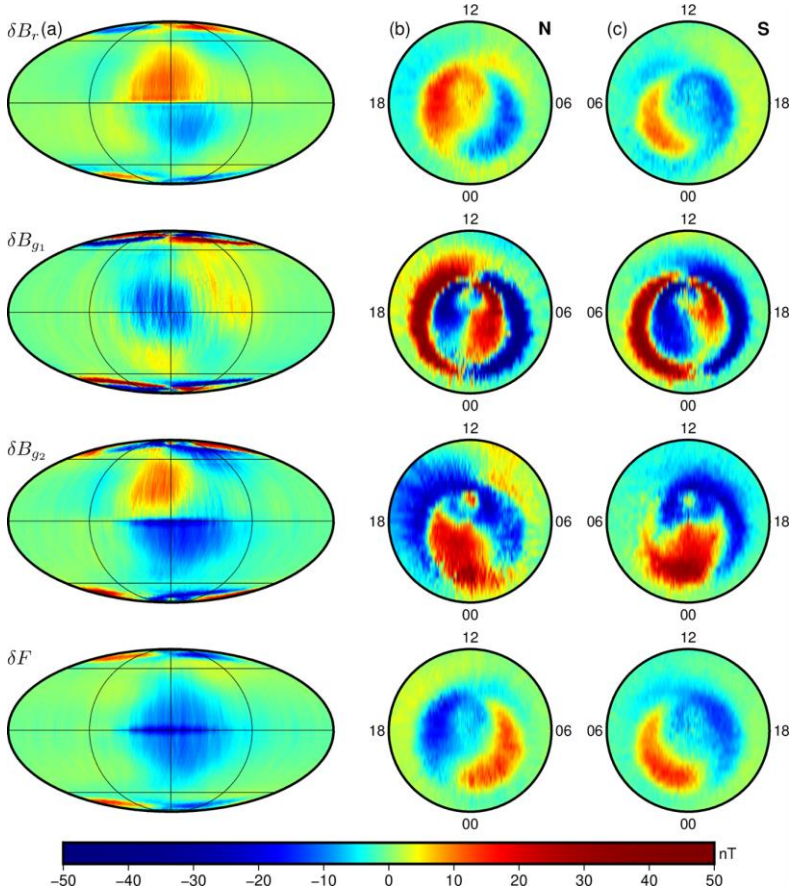
Outline

- Electrojet observations and modeling history
- Methodology
- Rotated current loops in QD coordinates
- SH representation
- Covariance between current loops
- PCA and resulting basis functions
- Application: long-period electrojet signals seen in Swarm data

Swarm observations of electrojets

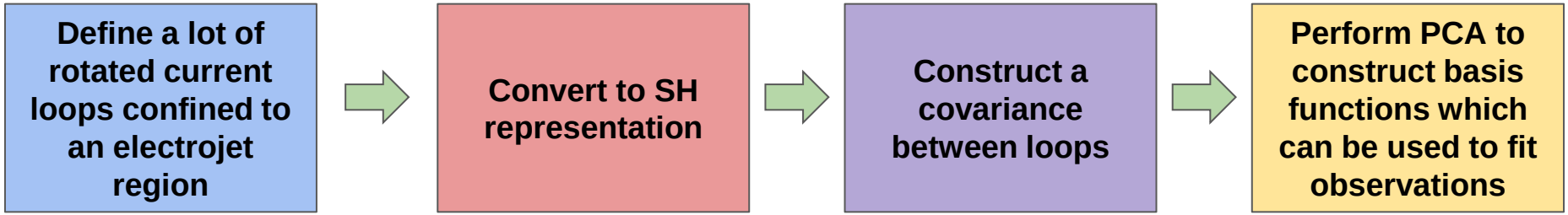
- Swarm A mean ionospheric signal over six years
- January 1, 2017 to December 31, 2022
- Data binned with respect to QD Latitude and MLT



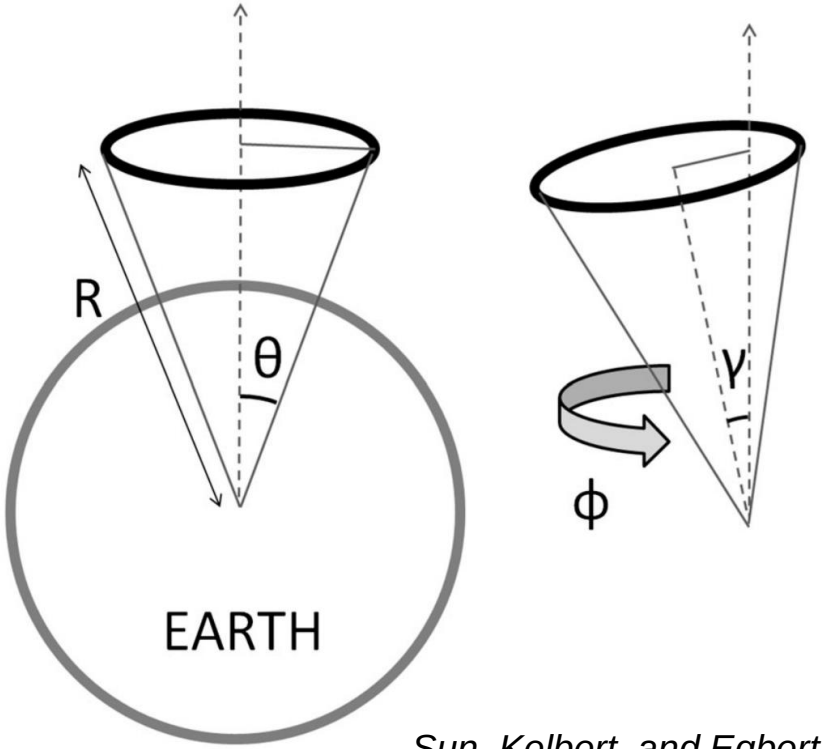
Empirical electrojet modeling methods and history

1D	2D	3D
Line Currents Olsen 1996 Ritter et al, 2003 Lühr et al, 2004 Alken et al, 2013, 2015 Aakjaer et al, 2016	**Spherical Harmonics** Haines, 1985 Sabaka et al, 2002 Torta et al, 2020	
1DSECS Vanhämaki et al, 2003 Juusola et al, 2006 Vanhämaki et al, 2020	**2DSECS** Amm 1997 Amm and Viljanen, 1999 Pulkkinen et al, 2003	
	PCA of current loops Sun, Kelbert and Egbert, 2015 This study	**Stay tuned…**

Methodology



Rotated current loops



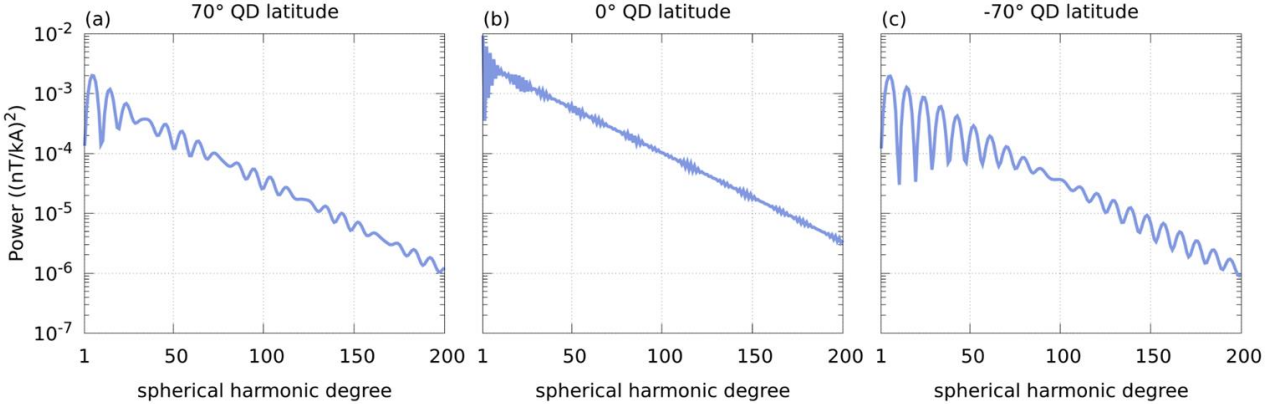
- Perform a large number of rotations to allow current flow in many different directions, with a preference for QD zonal flow

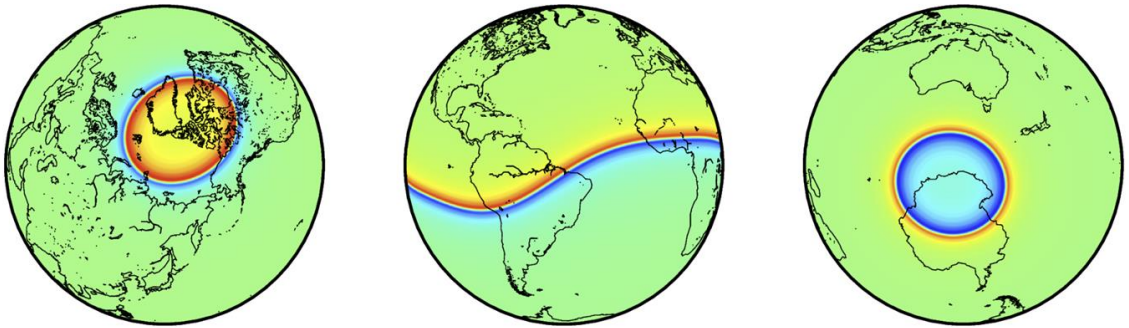
$$L_{final} = R_z(\eta)R_y(\psi)L_0$$

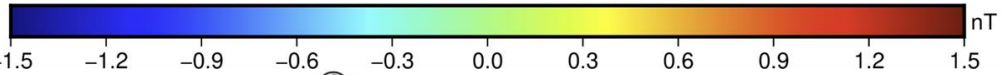
- η,ψ are rotation angles for the loops in QD coordinates

Sun, Kelbert, and Egbert, JGR, 2015

SH Representation of a single loop







SH degree/order 90 for Swarm altitude

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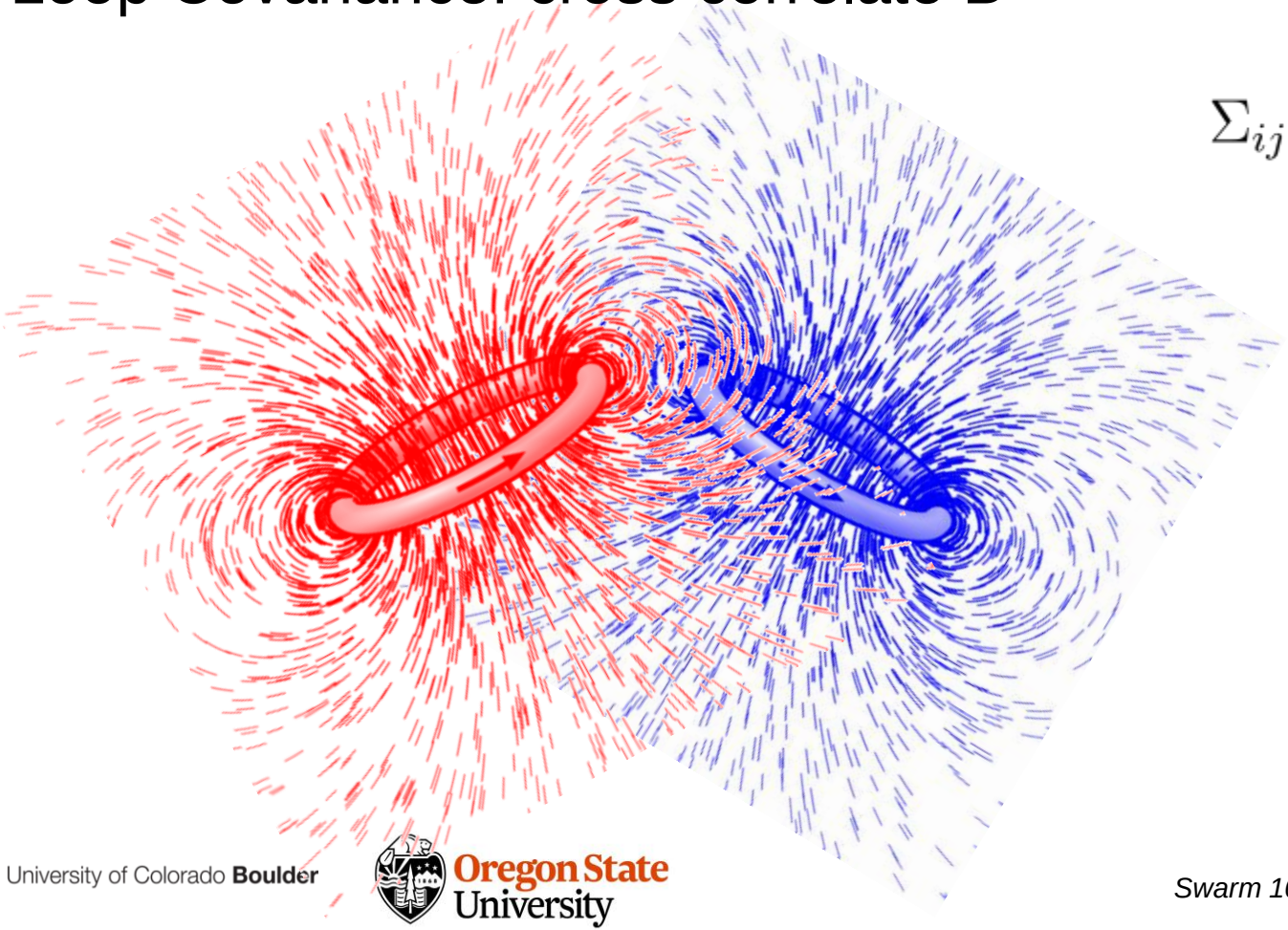
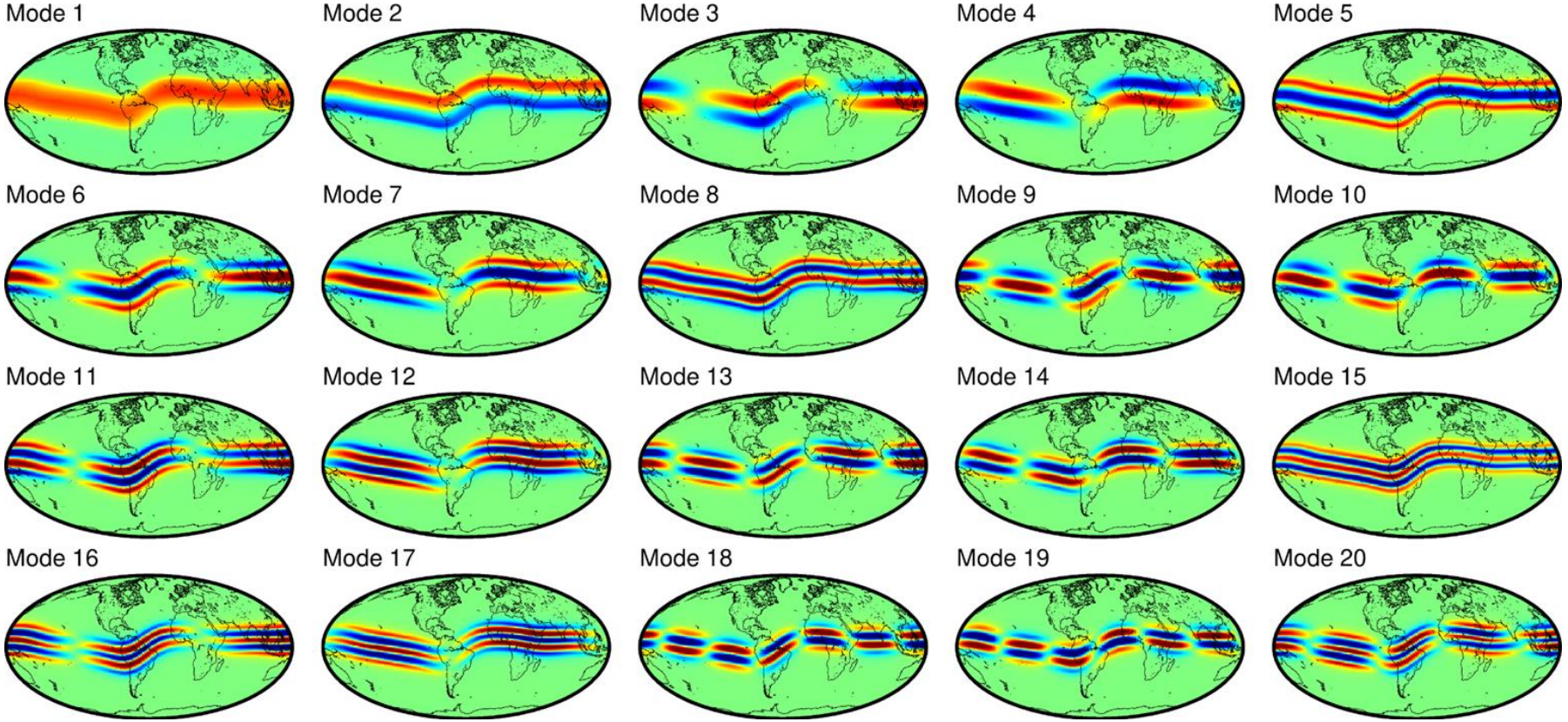
Loop Covariance: cross correlate B

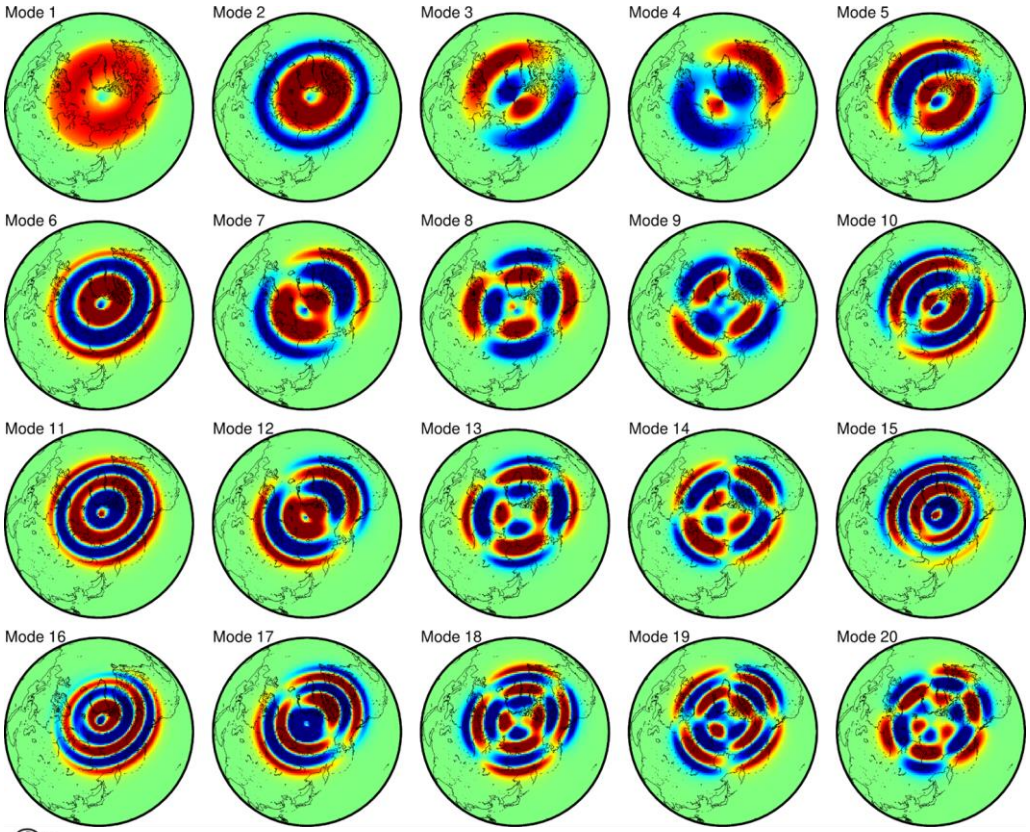


$$\Sigma_{ij} = \int \mathbf{B}_i \cdot \mathbf{B}_j d^3 r$$

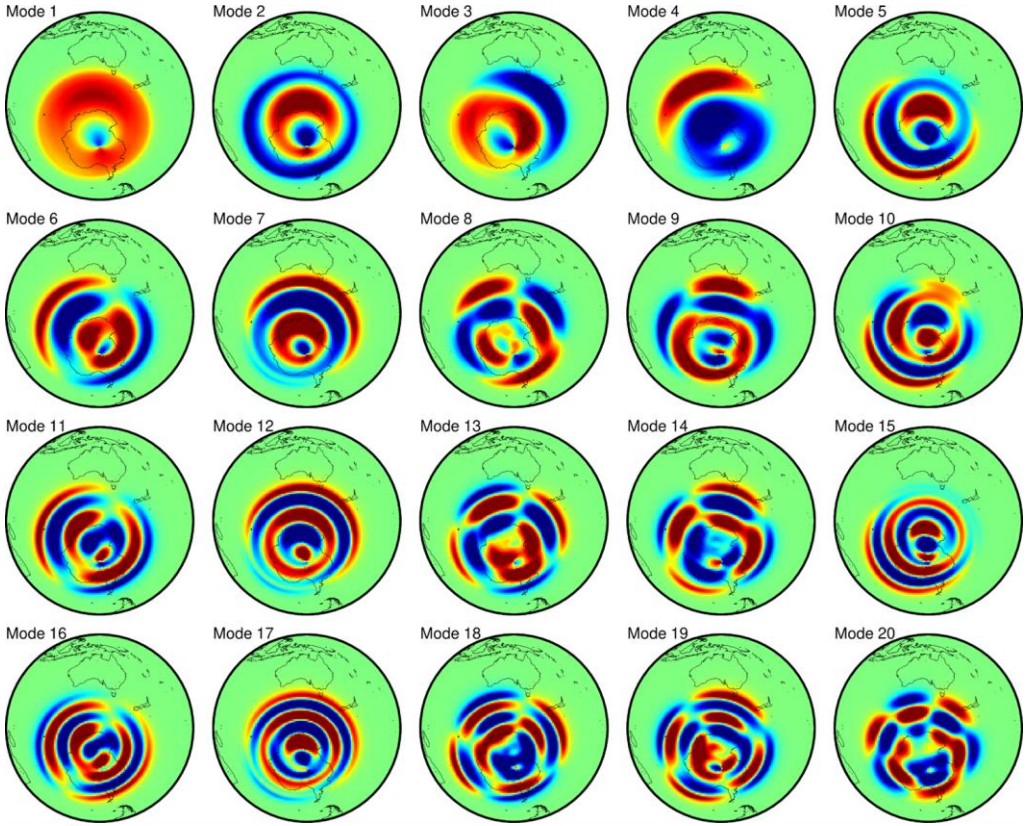
Equatorial modes (surface Bx component)



Northern modes (surface Bx component)

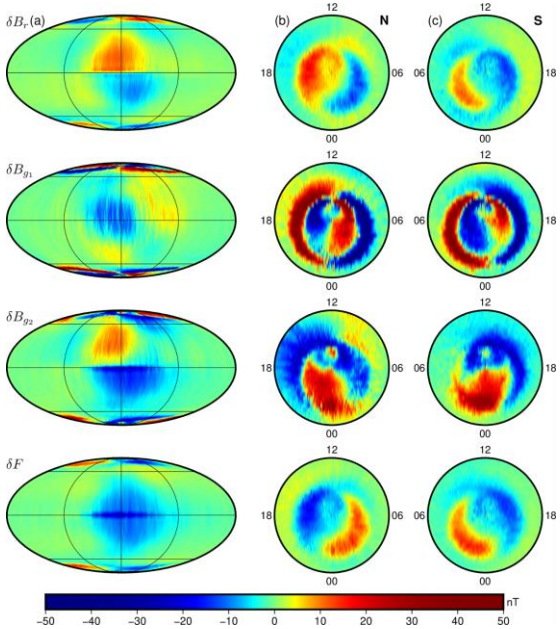


Southern modes (surface Bx component)



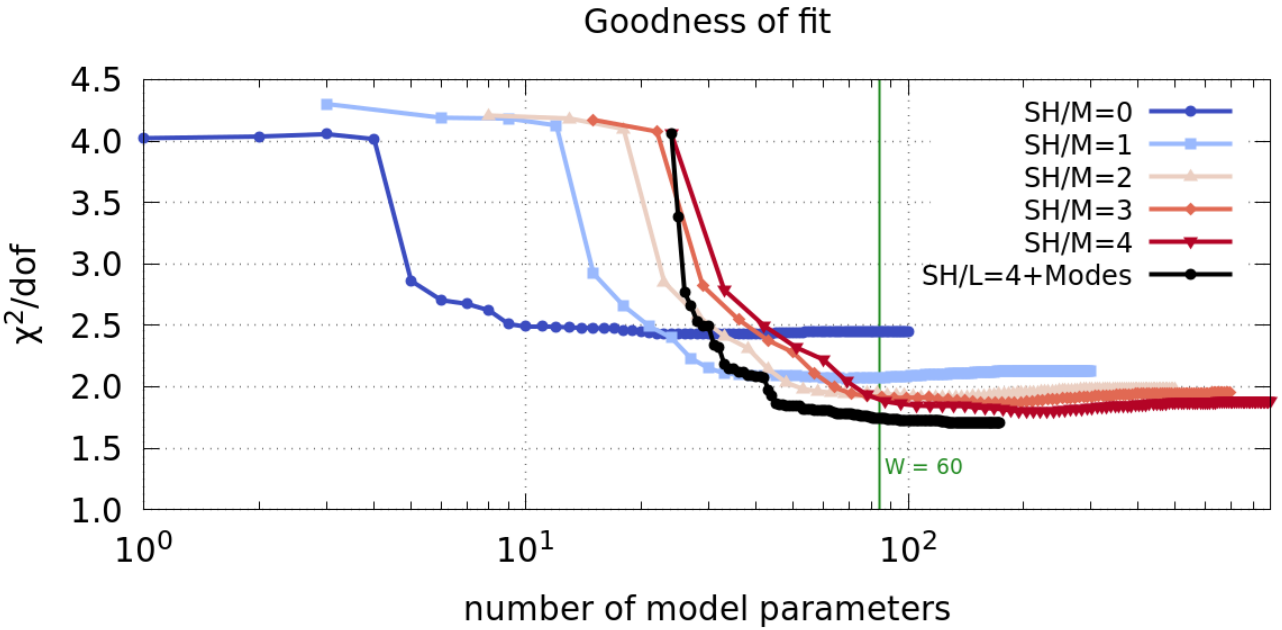
Application: fitting long-period electrojet signals

$$\mathbf{B}^{source}(\mathbf{r},t) = \sum_{i=1}^{W} \alpha_i \mathbf{\Xi}_i(\mathbf{r})$$



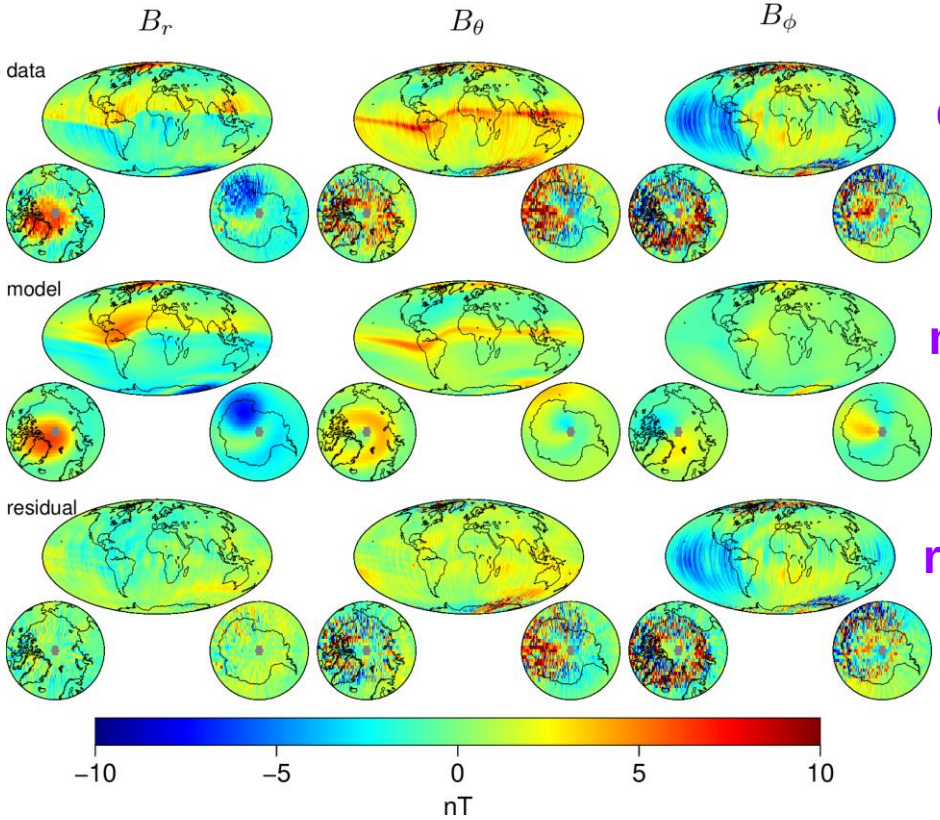
- Fit the mean ionospheric signal seen by Swarm over six years
- First term fits our new electrojet basis functions
- Second term is a low degree/order (L,M=4) SH model to capture mid-latitude Sq signals
- Model is regularized using the loop covariance matrix

Application: goodness of fit analysis



- Full model: L,M=4, W=60, **84** total model parameters
- SH only model: L=25,M=4, **213** model parameters

Data, fitted model, and residuals



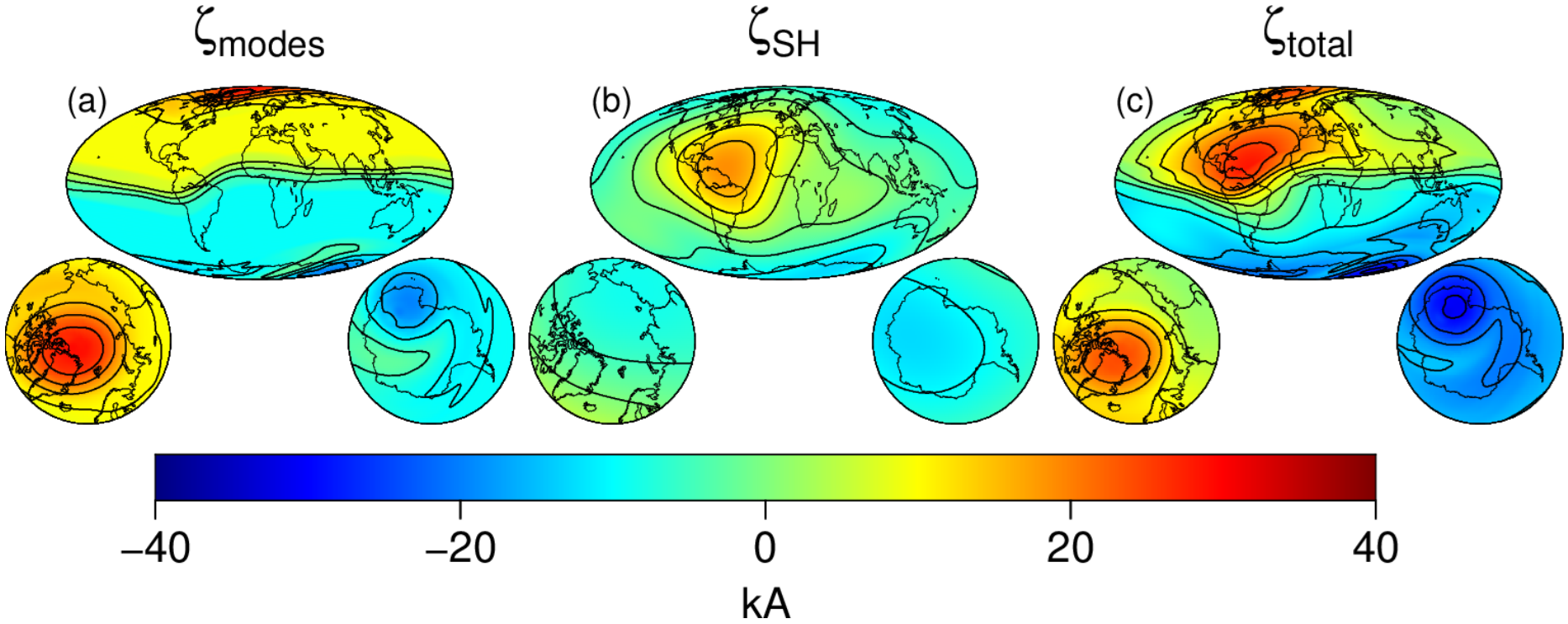
data

model

residual

Region	Satellite	Component	N	μ (nT)	σ (nT)	rms (nT)
$\lvert\lambda_q\rvert \leq 55°$	Swarm A	B_r	39639	0.08	1.12	1.12
		B_θ	39639	1.28	0.92	1.57
		B_ϕ	39639	-0.57	1.92	2.00
	Swarm B	B_r	39631	-0.06	1.08	1.08
		B_θ	39631	1.23	0.90	1.52
		B_ϕ	39631	-0.45	1.90	1.95
$\lvert\lambda_q\rvert > 55°$	Swarm A	B_r	23001	0.28	1.64	1.67
		B_θ	23001	0.65	4.44	4.49
		B_ϕ	23001	0.32	5.43	5.44
	Swarm B	B_r	23729	0.18	1.57	1.58
		B_θ	23729	0.42	4.48	4.50
		B_ϕ	23729	0.40	5.48	5.50

Application: equivalent current stream function at 110km



Summary

- We have developed a novel method of constructing basis functions to fit toroidal currents in the electrojet regions
- Our basis functions are fully 2D, and are based on PCA of a large number of rotated current loops
- We have applied these new functions to fit long-period signals in all 3 electrojet regions simultaneously

Next Steps

- Fit shorter period electrojet signals
  - Orbit-by-orbit fits to Swarm A/C pair
- Simulations with Nanomagsat to see if we can recover longitudinal gradients in the electrojet currents