SuperSynthIA: Physics-Ready Full-Disk Vector Magnetograms from HMI, Hinode, and Machine Learning

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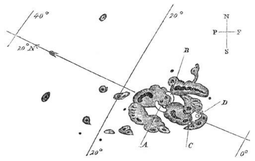
Motivation

Solar vector magnetograms, the map of magnetic field vectors on Sun's surface, are crucial for understanding and predicting solar activities like solar flares and coronal mass ejections. These activities impact space weather, satellite operation, communication system, and power grids. SuperSynthIA advances our ability to monitor and understand solar activities.



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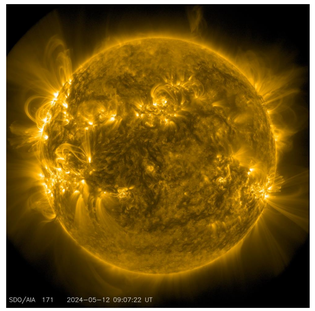
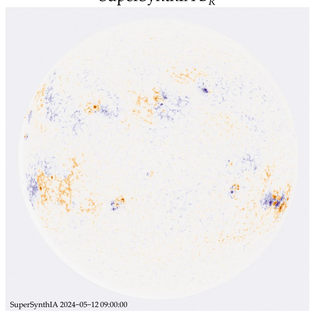
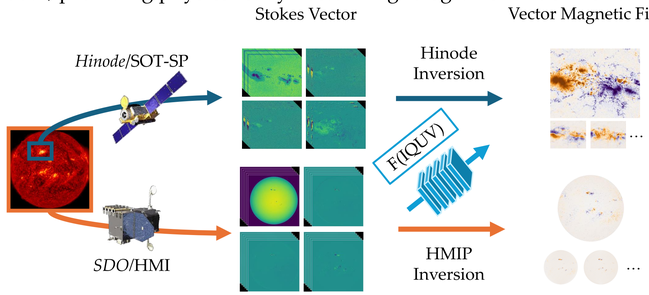
SuperSynthIA B_R





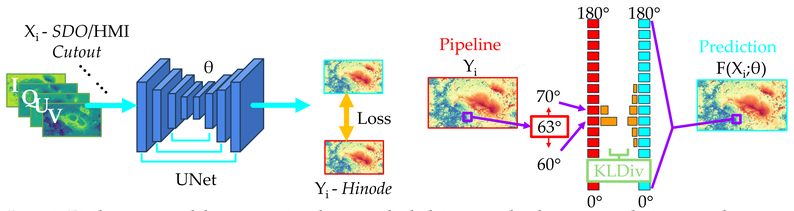
Key Idea

Solar magnetic fields are estimated by observing polarized light and then applying optimization methods. Different instruments produce results with different tradeoffs. Given two satellites with complementary missions that co-observe the sun for over a decade, we train networks to merge the strengths of both, providing physics ready vector magnetograms for downstream tasks.

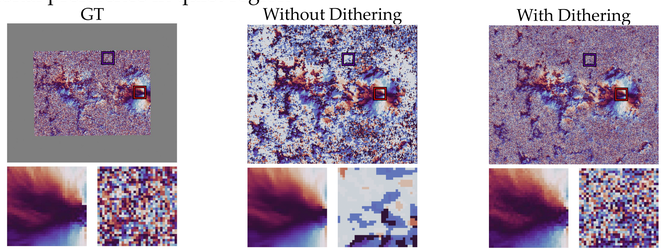


Approach

UNet + Regression by Classification w/ adaptive bins to mitigate underestimation



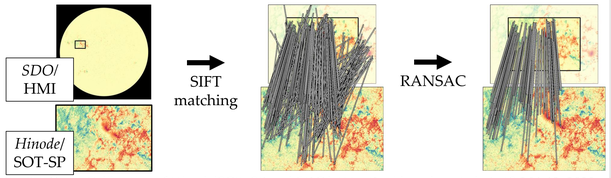
Logit Dithering add noise to log-probabilities, which is used to resolve directional preference in quiet region



Multiple methods: Direct or Analytic method to produce disambiguated components (αB_R , αB_Φ , αB_θ) – estimate components in gravity frame or sky frame

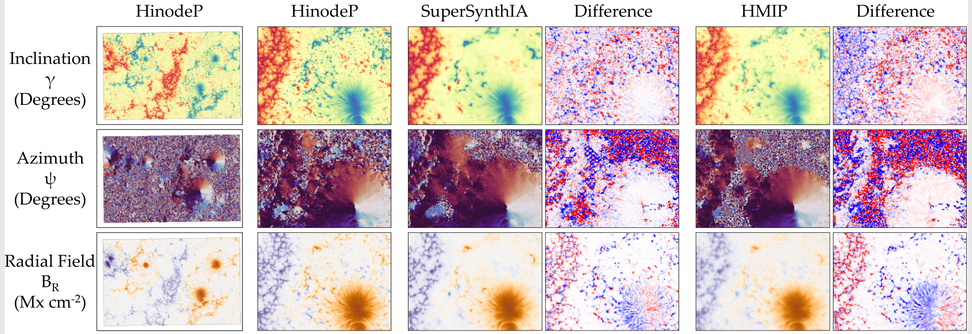
Data

Dataset: 13.4K aligned scans over a decade using SIFT + Optical Flow



For details, check *Large-Scale Spatial Cross-Calibration of Hinode/SOT-SP and SDO/HMI. David Fouhey et al. ApJS 264:49. 2023*

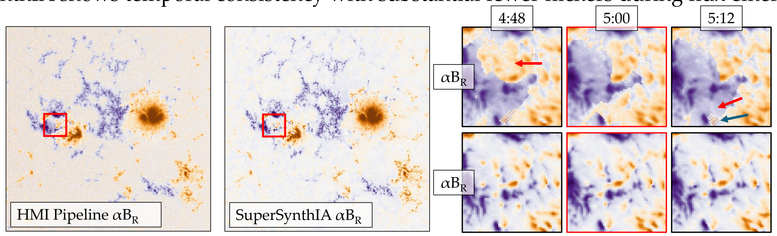
Result



Using HinodeP as ground truth, we report mean absolute error (MAE), and fraction of pixels correct to within an empirical threshold t (% < t)

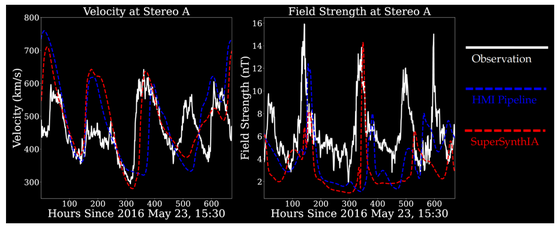
		Inclination(γ)		αB_R		αB_Φ		αB_θ	
		MAE	% < t	MAE	% < t	MAE	% < t	MAE	% < t
Equat	SuperSynthIA	9.7	42.2	33.1	81.3	25.7	76.6	24.3	74.4
(non-polar)	HMIP	11.2	36.2	54.6	57.9	59.6	30.2	67.3	24.8
Equat1K	SuperSynthIA	3.4	82.9	160.4	22.1	150.7	17.9	97.9	24.8
(wo quiet region)	HMIP	6.8	54.6	181.9	19.0	153.8	18.1	116.4	19.2

SuperSynthIA shows temporal consistency with substantial fewer flickers during flux emergence



Applications

SuperSynthIA can be useful in various downstream tasks. Here we show one example, the solar wind prediction. SuperSynthIA mimics the observation trend well.



One more thing…

SuperSynthIA will be integrated into the SDO/HMI pipeline soon!

JSOC SDP