



Argo Trajectories Reveal Changing Core-Peripheral Partitioning of Gulf Stream Transport

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Abstract. Long-term Gulf Stream transport estimates diverge, partly because existing observing systems sample different
15 locations and cross-stream extents. Most studies assess transport at fixed sections, leaving changes in the core and surrounding flow unresolved. Here, we develop a Core-Peripheral Transport Decomposition Method using Argo float trajectories from 2003 to 2024. We identify the mean core band from velocity gradients and quantify core-band and peripheral transport from annual mean time series. Core-band transport shows no significant trend, while peripheral transport declines at -4.99 Sv yr^{-1} before 2017 and recovers at $+20.01 \text{ Sv yr}^{-1}$ afterward. The core fraction of the fixed-latitude total
20 rises from approximately 33% to more than 100% in 2015 and 2019, before decreasing to 26% at the end of the record. Validation against shipboard ADCP observations yields significant interannual correlation ($R = 0.667$). These results reveal changing cross-stream transport partitioning and provide an observational basis for interpreting divergent Gulf Stream transport estimates across observing systems.

1 Introduction

25 The Gulf Stream is among the most powerful western boundary currents. As the upper limb of the Atlantic Meridional Overturning Circulation (AMOC), it transports warm water northward and influences North Atlantic and global climate (Bryden et al., 2005; Buckley and Marshall, 2016). Changes in its transport affect sea level on the U.S. East Coast (Ezer, 2019), European climate, and air-sea fluxes.

Existing long-term transport trends differ. Piecuch and Beal (2023) reported a weakening of $\sim 1.2 \pm 1.0 \text{ Sv}$ from Florida
30 Strait cable measurements over 1982–2022. Volkov et al. (2025) extended the Florida Current record after the 2023 cable



failure and found it stable. Volkov et al. (2024) found no trend after geomagnetic correction. Acoustic Doppler Current Profiler (ADCP) observations from the Oleander vessel likewise showed no trend (Rossby et al., 2019).

Previous studies have focused on along-stream variability and path shifts. Along-stream transport can vary substantially along the Gulf Stream path, with significant increases downstream of Cape Hatteras (Heiderich and Todd, 2020). Torres-Córdoba and Valle-Levinson (2025) found non-uniform transport along the Florida shelf. Upstream sections weaken, whereas downstream sections remain stable. Asbjørnsen et al. (2024) cautioned against using a single section to infer large-scale changes. Path shifts have also been widely documented. Wang et al. (2022) revealed a "see-sawing" pattern in the Gulf Stream path, with northward shifts upstream and southward shifts downstream. Core axis tracking studies identified a southward shift (Zhang et al., 2020; Sánchez-Román et al., 2024), which van Westen and Dijkstra (2026) linked to AMOC weakening. However, the cross-stream partitioning between core and periphery remains unquantified. When the Gulf Stream meanders, fixed sections may record apparent changes from axis shifts rather than true strength changes (Gangopadhyay et al., 2016). Most of the cross-track velocity variance comes from meandering rather than from rings or complex profiles (Kelly, 1991), and the transport measured at one location is often incoherent with transport only ~200 km away (Sturges and Hong, 2001).

Since the early 2000s, the global Argo network has provided sustained, spatially extensive observations of both the Gulf Stream and its surrounding waters (Park et al., 2005; Goes et al., 2020; Ollitrault et al., 2022). Here, we use Argo trajectories from 2003 to 2024 to examine how Gulf Stream transport is partitioned between the core band and the peripheral region. We develop a Core-Peripheral Transport Decomposition Method that reconstructs trajectory-derived velocity fields, identifies the mean core band from velocity gradients, and calculates transport using two complementary section geometries. This framework allows us to assess the spatial and temporal evolution of cross-stream transport partitioning and its implications for interpreting Gulf Stream variability. The method is transferable to other boundary currents with strong lateral structure, providing a practical approach to reconciling transport estimates from observing systems with different cross-stream coverage

2 Data and methods

2.1 Study region and data

The study region spans 35°N–40°N, 55°W–75°W, covering the Gulf Stream extension after Cape Hatteras (Figure 1). We used Argo trajectories from the Global Data Assembly Centres (Argo GDAC) for 2003–2024. These floats drift with ocean currents and cycle between the sea surface and a parking depth, transmitting position and hydrographic data via satellite at each surface interval. After quality control, data from 150 floats yielded 267,853 surface and 21,023 subsurface velocity points across the full dataset. Within the study region, 61,084 surface and 4,411 subsurface points were retained. Seafloor depths along the transport sections were constrained using the General Bathymetric Chart of the Oceans (GEBCO) bathymetry at 15 arc-second resolution

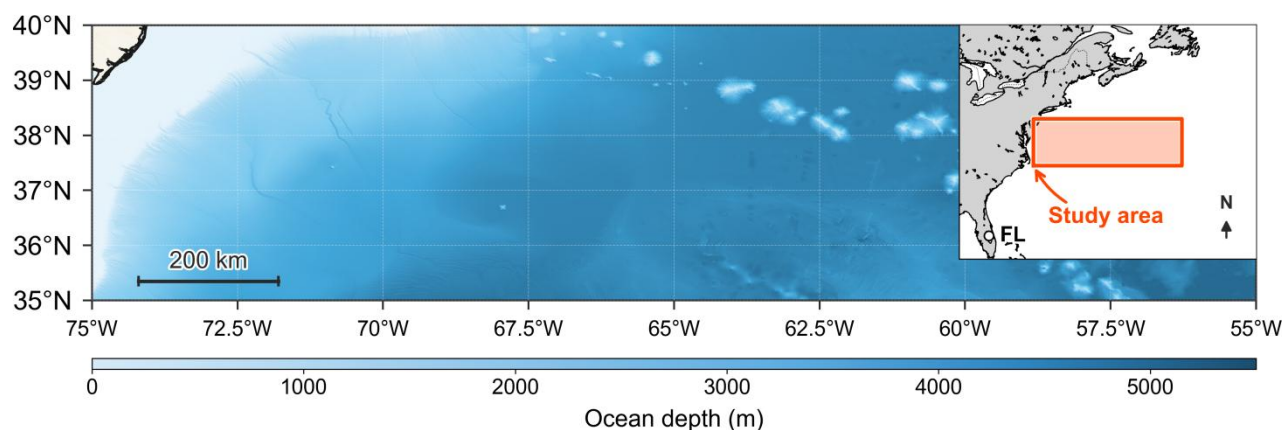


Figure 1. Bathymetry of the study region in the western North Atlantic. The main map shows the study area (35°N–40°N, 55°W–75°W), covering the Gulf Stream extension after Cape Hatteras, with ocean depth indicated by the colorbar. The inset shows the location of the study area, marked by the red box. Bathymetry data are from GEBCO (<https://www.gebco.net/>). Map lines delineate study areas and do not necessarily depict accepted national boundaries.

2.2 Surface and subsurface velocities from Argo measurements

Argo float trajectories contain high-frequency inertial oscillations superimposed on the low-frequency background advection of the surrounding water. We therefore applied the cycle-synchronized spatiotemporal extrapolation method adapted from Park et al. (2005) to separate these components and derive surface and subsurface velocities. For each float cycle, we fitted the surface trajectory to a model combining linear background advection and inertial oscillations, then extrapolated the unobserved positions at the start of descent and the end of ascent. We calculated surface-segment velocities from the displacement and time interval between each pair of consecutive satellite fixes. For each complete cycle, we calculated the subsurface cycle-mean velocity as the displacement between the two extrapolated endpoints divided by the corresponding elapsed time. Each subsurface velocity is assigned to the parking depth of the corresponding float cycle. This procedure provides synchronized surface and subsurface velocity estimates directly from float trajectories (Park et al., 2005; Ollitrault et al., 2022).

2.3 Identification of the mean gulf stream core band

The Gulf Stream exhibits rapid velocity decay from the core axis outward, generating large velocity gradients on both flanks. Using the surface velocity component from Argo trajectories, we computed the gradient field to delineate the core band boundary, where the highest gradient values mark its extent. The gradient field was computed on a regular grid with 0.025° latitude $\times$ 0.1° longitude spacing. Similar approaches can be applied to identify boundary current cores (Belkin and O'Reilly, 2009; Andres et al., 2020):.



$$|\nabla V| = \sqrt{\left(\frac{\partial V}{\partial x}\right)^2 + \left(\frac{\partial V}{\partial y}\right)^2}, \quad (1)$$

where V is the velocity magnitude and partial derivatives are computed using central differencing.

Since gradient magnitude varies with longitude, a fixed threshold is inadequate. We applied a percentile threshold, classifying the top 10% of gradient values as the core band. This threshold captures the upper tail while maintaining spatial contiguity across most longitudes (Section 3.2). At each longitude, we extracted the gradient-weighted mean latitude as the centerline and computed the perpendicular span. The core band boundary was defined as the centerline $\pm$ half the band width.

2.4 Core-Peripheral transport decomposition

Following section flux integration (Wunsch, 1996; Cunningham et al., 2007), we designed two complementary section layouts. In the core-band-oriented method, section centers follow the core centerline with endpoints set by band width, capturing core transport. In the spatially fixed method, endpoints are fixed at 35° N and 40° N, quantifying total regional transport. Both schemes are at identical longitudes. Their difference yields peripheral transport.

For each section, we constructed a 100-km buffer on both sides, projected velocity observations within the buffer onto the section plane, and divided the section grid into four depth layers (Figure 2) : 0 – 300 m, 300 – 1500 m, 1500 – 2200 m, and 2200 – 6000 m. The four layers reflect the vertical sampling of Argo. Each of the first three layers has an interpolation target depth of 0, 1000, and 2000 m, respectively. The 0 – 300 m layer is constrained by surface-segment velocities at every float cycle. The 300 – 1500 m layer is constrained by subsurface cycle-mean velocities from float cycles with parking depths in this range. The 1500 – 2200 m layer is constrained by cycles with parking depths between 1500 m and 2200 m, which account for the largest share of subsurface estimates. The 2200 – 6000 m layer contains no direct Argo velocity observations and is filled by linear interpolation from adjacent layers.

Within each layer, projected observations were assigned to the corresponding grid cells. When multiple observations fell within the same cell, their velocities were interpolated using inverse distance weighting (IDW). Cells containing a single observation were assigned that velocity directly. Empty cells within each layer were filled by linear interpolation, and the same method was applied between adjacent layers to obtain velocity values throughout the water column. Cells below the seafloor were assigned zero velocity, and the local bottom depth was constrained by GEBCO bathymetry. The volume transport across each section was calculated by discrete summation:

$$Q = \sum_{i=1}^{N_L} \sum_{j=1}^{N_D} V_n(i,j) \Delta L \Delta D, \quad (2)$$

where V_n is the section-normal velocity, with i and j indexing the horizontal and vertical discrete elements. The horizontal and vertical sampling intervals are $\Delta L = 100$ m and $\Delta D = 50$ m.

For the core-band-oriented method, we deployed 100 sections at uniform longitude intervals from 55 ° W to 75 ° W, perpendicular to the core axis. Each section center lies on the core band centerline, with endpoints extending half the band width on each side.

The spatially fixed method positions sections at the same longitudes, with endpoints fixed at 35°N and 40°N, independent of the core axis. Peripheral transport is defined as the total transport from the spatially fixed sections minus the core-band transport.

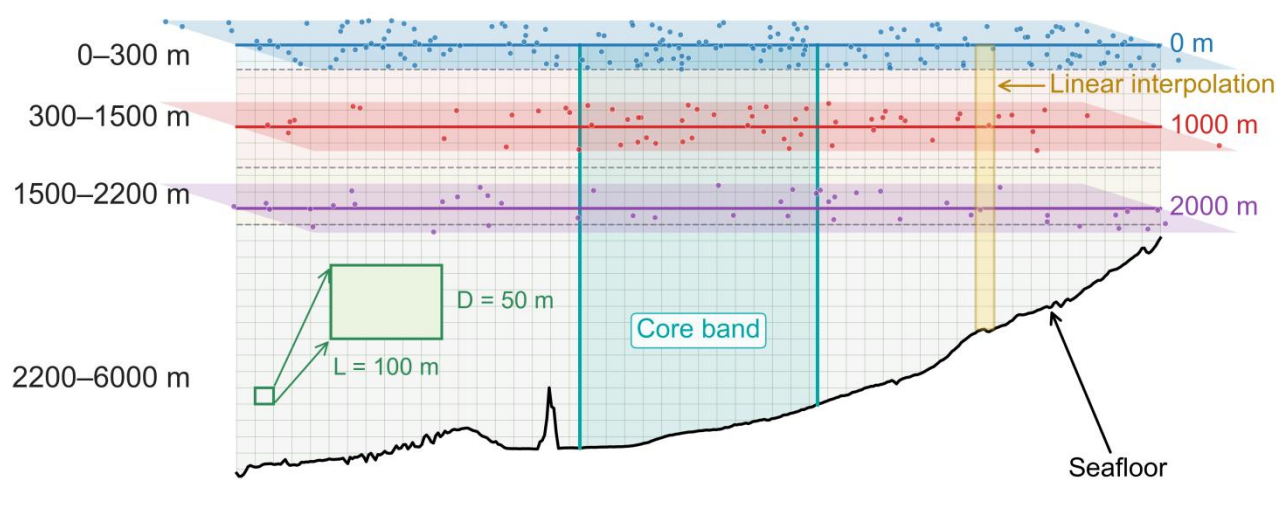


Figure 2. Schematic of the core-peripheral transport decomposition across a Gulf Stream section. The four shaded bands represent the four depth layers (0–300, 300–1500, 1500–2200, and 2200–6000 m). The first three layers have interpolation target depths of 0, 1000, and 2000 m, shown as the three horizontal planes. The green rectangle shows the grid size, with horizontal and vertical sampling intervals of $L = 100$ m and $D = 50$ m. Within each grid cell, multiple observations are combined by inverse distance weighting (IDW), and empty cells are filled by linear interpolation. The vertical yellow rectangle marks the linear interpolation applied within and between layers. The mean core band is shown as the light cyan shaded area. The black solid line represents the seafloor topography.

2.5 Construction of annual transport estimates

We constructed transport time series at annual resolution. For each calendar year from 2003 to 2024, we pooled all observations within the year to build the velocity field and calculated section transport at each of the 100 longitudes. Averaging across sections yielded annual transport series for the core band, the peripheral region, and the fixed-latitude total, each with 22 annual values.



3 Results

3.1 Spatial distribution of Argo-derived surface and subsurface velocity fields

The study region covers 382 valid $0.5^\circ \times 0.5^\circ$ grid cells (Figure 3). Surface velocity data coverage was adequate. Each valid
 135 grid cell contained approximately 160 velocity points, with a maximum of 369 points per cell, sufficient to capture the
 spatial morphology of the Gulf Stream path. Subsurface data density was higher near the core band, averaging about 12
 velocity points per valid grid cell, with a maximum of 27 points, enough to resolve the core band's vertical structure.

The surface velocity field shows the Gulf Stream extending northeastward after leaving the coast, with the fastest core band
 located on the southern flank of the core axis. The core band reaches maximum velocities of about 1.4 m s^{-1} . The velocity
 140 distribution exhibits strong spatial concentration, with rapid decay on both sides of the axis, a characteristic pattern of
 western boundary currents. The mean surface velocity is about 0.62 m s^{-1} . The subsurface velocity field shows a similar
 spatial structure, though with markedly reduced magnitudes. The core band reaches about 0.4 m s^{-1} , reflecting the vertical
 decay of strong currents with depth.

The continuous velocity band along the Gulf Stream path in Figures 3c and 3d demonstrates that the velocity field
 145 reconstructed from Argo trajectories captures the dynamical structure of the Gulf Stream extension.

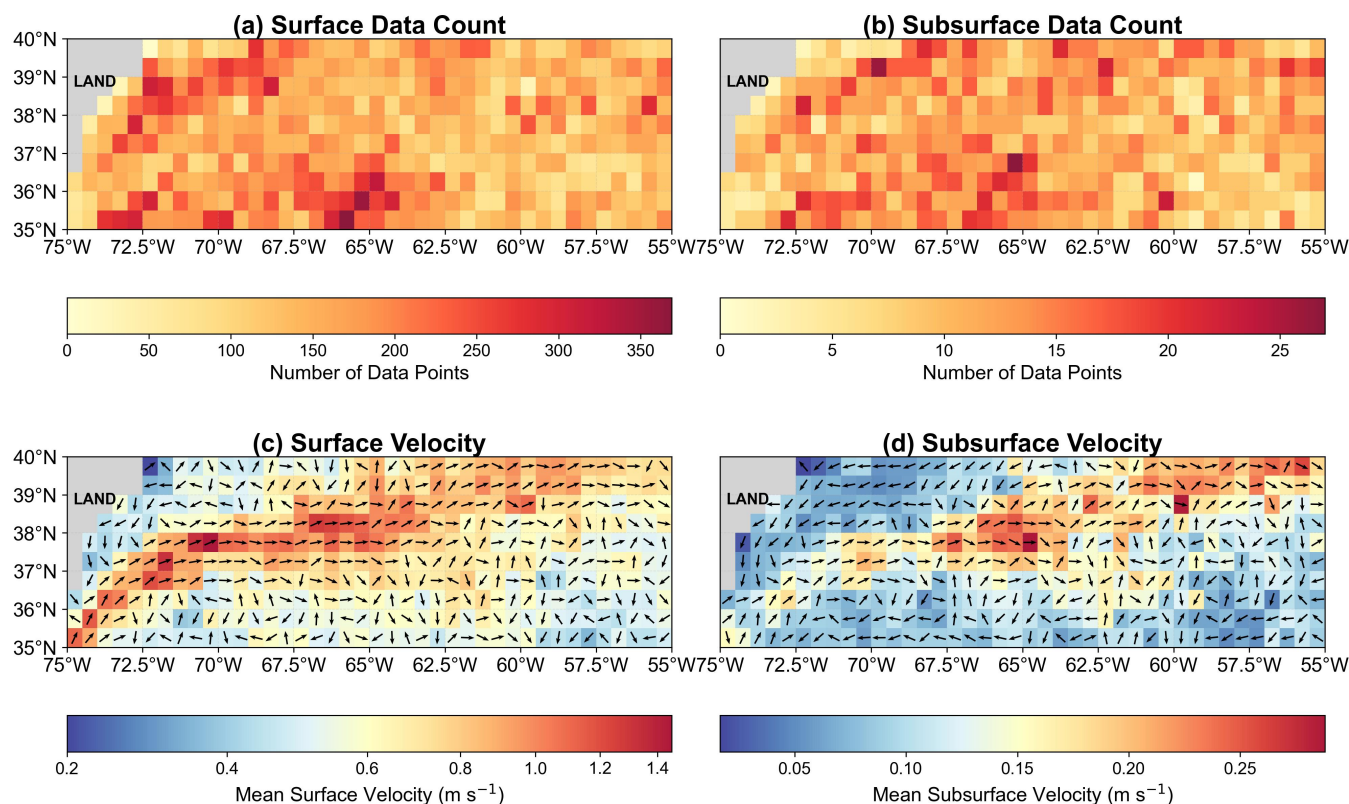




Figure 3. Spatial distribution of Argo-derived surface and subsurface velocity fields. (a) Surface velocity data count; (b) Subsurface velocity data count; (c) Surface velocity spatial distribution; (d) Subsurface velocity spatial distribution.

3.2 Spatial structure of the Gulf Stream core band

150 The spatial distribution of the velocity gradient field reveals that the core band forms a continuous ribbon-like structure aligned with the Gulf Stream path. Gradient magnitudes decrease from the band center outward. In the central region, gradient values exceed $9 \times 10^{-5} \text{ s}^{-1}$, dropping sharply to below $4 \times 10^{-5} \text{ s}^{-1}$ in the peripheral region. The transition from high to low gradient magnitude occurs near $7.9 \times 10^{-5} \text{ s}^{-1}$, corresponding to the top 10% of the gradient magnitude distribution. Regions above this threshold remain continuous over 99% of longitudes, representing the portion of the Gulf Stream with the
 155 strongest velocity gradients. The mean width of the core band is 142.6 km (Figure 4).

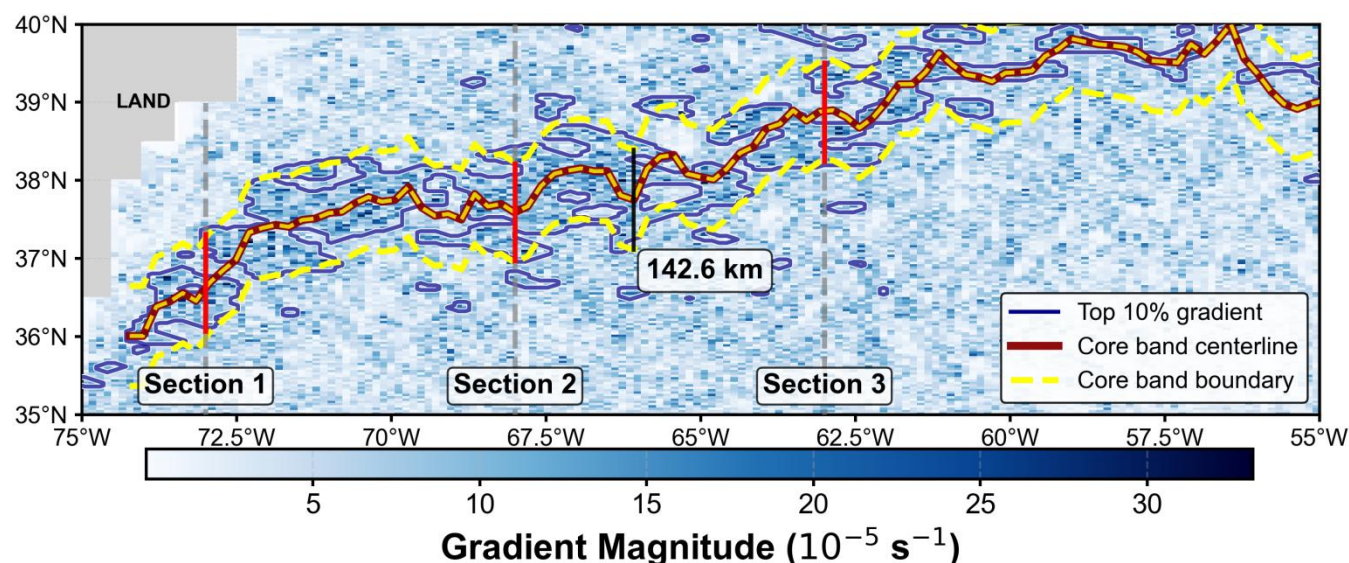


Figure 4. Velocity gradient field derived from surface velocities. The core band centerline (red) and boundaries (yellow) are shown. Three cross-sections are marked: Section 1 at 73°W, Section 2 at 68°W, and Section 3 at 63°W.

3.3 Downstream changes in core-peripheral transport partitioning

160 Transport distributions at three sections marked in Figure 4 reveal downstream changes in the core band (Figure 5), consistent with earlier synoptic sections that documented similar along-stream changes in transport and potential vorticity (Leaman et al., 1989).

The 73°W section is located in the upstream segment where the Gulf Stream is topographically constrained. The core band spans 36.0°N–37.3°N, centered at 36.6°N. Total transport is $81.2 \pm 2.1 \text{ Sv}$, with the core contributing 84.3% (Figures 5a, 5b).

165 The 68°W section lies in the transition zone where the Gulf Stream has separated from the continental slope. The core band spans 37.0°N–38.3°N, with a center latitude of 37.6°N. Total transport increases to $111.1 \pm 3.9 \text{ Sv}$ and core transport to 88.8



Sv, but the core contribution decreases to 79.9% as the peripheral region expands. Topographic constraint weakens, core concentration decreases, and the peripheral region accounts for more transport (Figures 5c, 5d).

The 63°W section is located in the open-ocean free jet segment. The core band spans 38.2°N–39.5°N, with a center latitude of 38.8°N. Total transport is 94.5 ± 4.3 Sv, and the core contribution drops sharply to 53.8%, roughly equal to the peripheral contribution (Figures 5e, 5f).

From 73°W to 63°W, the core contribution decreases from 84.3% to 53.8%, while the core band center latitude shifts northward from 36.6°N to 38.8°N. The decreasing core contribution and northward migration reflect broadening of the velocity field as the Gulf Stream transitions from a constrained boundary current to a free jet (Torres-Córdoba and Valle-Levinson, 2025).

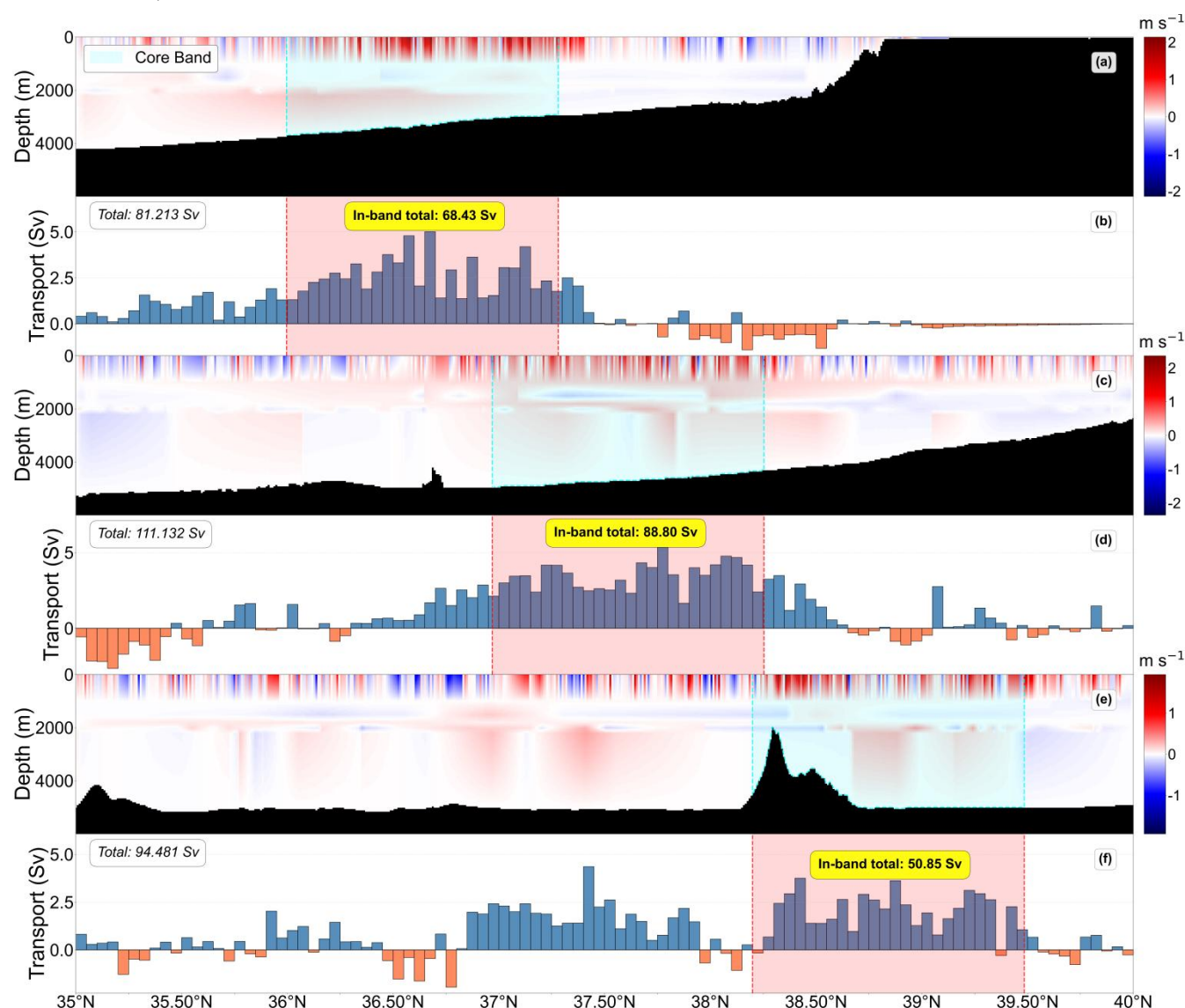




Figure 5. Transport distributions along the Gulf Stream at the three sections marked in Figure 4. (a) Velocity distribution at 73°W; (b) Latitudinal transport distribution at 73°W; (c) Velocity distribution at 68°W; (d) Latitudinal transport distribution at 68°W; (e) Velocity distribution at 63°W; (f) Latitudinal transport distribution at 63°W.

180 3.4 Distinct interannual variability of core-band and peripheral transport

Core and peripheral transport exhibit distinct interannual variability throughout the 2003–2024 record (Figure 6a). The core band has a mean of 47.26 Sv and a standard deviation of 11.69 Sv, and varies within ± 20 Sv of its mean with no sustained excursions. The peripheral region has a mean of 54.06 Sv and a standard deviation of 41.12 Sv, about 3.5 times that of the core band. Because the fixed-latitude total is the sum of the two components, its year-to-year variability is carried
 185 predominantly by the peripheral region. A single fixed-section time series therefore mixes a component without a significant trend with a highly variable one.

The peripheral component undergoes a reversal in 2017 (Figure 6b). The pre-2017 segment declines at -4.99 Sv yr^{-1} with $p = 0.004$, while the post-2017 segment recovers at $+20.01 \text{ Sv yr}^{-1}$ with $p = 0.041$. The core band shows no significant trend in either segment. The reversal is confined to the peripheral component, while the core shows no significant trend, so the two
 190 components cannot be treated as a single dynamical quantity.

The two contrasting behaviours change how the fixed-latitude total is partitioned (Figure 6c). During the pre-2017 decline, the peripheral contribution shrinks while the core band shows no significant trend, and the total is increasingly accounted for by the core. After 2017, the peripheral contribution recovers, and the partition shifts back. Across the 22-year record, the peripheral contribution is positive in 20 years and negative in only 2015 and 2019, so that the fixed-latitude total falls below
 195 the core-band transport by 1.04 Sv and 2.50 Sv, respectively.

The changing partition is expressed in the core fraction of the fixed-latitude total (Figure 6d). The core fraction has a mean of 54.33% and a standard deviation of 23.03% over the record, with 9 years above the mean and 13 years below it. It rises from 33.24% in 2003 to 102.71% in 2015 and 106.13% in 2019, before decreasing to 25.54% in 2024. A fixed-section observer who monitors the fixed-latitude total would report a declining Gulf Stream before 2017 and a recovering one
 200 afterward, while an observer who monitors the core fraction would see the opposite pattern, even though the core transport itself shows no significant trend.

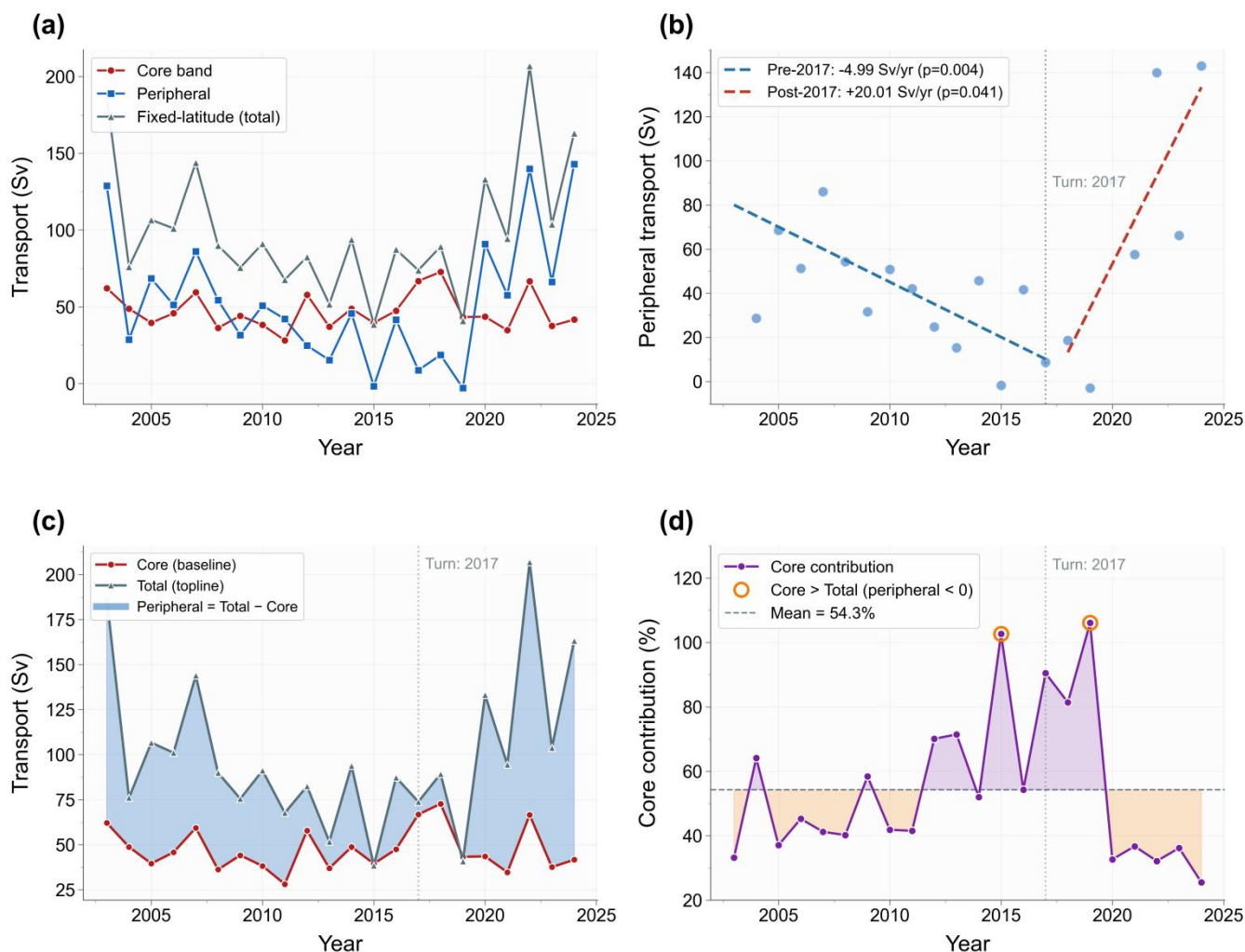


Figure 6. Core-peripheral transport evolution and core contribution. (a) Annual mean transport of the core band, peripheral region, and fixed-latitude total from 2003 to 2024. (b) Peripheral transport with pre-2017 and post-2017 linear fits. Pre-2017 slope: -4.99 Sv yr^{-1} ($p = 0.004$, $n = 15$); post-2017 slope: $+20.01 \text{ Sv yr}^{-1}$ ($p = 0.041$, $n = 7$). (c) Decomposition of the fixed-latitude total into core-band (baseline) and peripheral (shaded) components. The blue shaded area represents a positive peripheral transport. (d) Core contribution (core band divided by fixed-latitude total) over the study period. Orange shading marks years when the core contribution falls below the record mean; orange circles mark years when the core-band transport exceeded the fixed-latitude total (2015 and 2019).

3.5 Validation of argo-derived transport estimates

To evaluate the Park method here, we computed its extrapolation error. Using the first k position points from each float cycle, we fitted the model and extrapolated the next position. The median extrapolation error was 1.293 km ($\sim 0.16 \text{ cm s}^{-1}$), consistent with Park et al. (2005) for similar oceanic regions.

- 215 We used shipboard ADCP (SADCP) observations from the University of Hawaii Sea Level Center to validate our transport estimates over the overlapping period of 2003–2018 along the oblique section from 35°N , 66.7°W to 40°N , 73.5°W , with 551,079 velocity points in the study region (Figure 7). To reduce bias from uneven monthly sampling, we retained only years with at least six months of SADCP coverage ($n=12$). The two datasets show a moderate but statistically significant interannual correlation ($R = 0.667$, $p = 0.018$). Argo estimates have a bias of -7.35 Sv relative to SADCP, $\sim 7\%$ of Gulf Stream transport.
- 220 Stream transport. This discrepancy may arise from differences in sampling representativeness. Argo trajectories record discrete quasi-Lagrangian velocity samples, whereas SADCP sections provide instantaneous Eulerian velocity distributions. Despite this bias, the interannual correlation indicates that Argo estimates capture relative changes and decadal patterns.

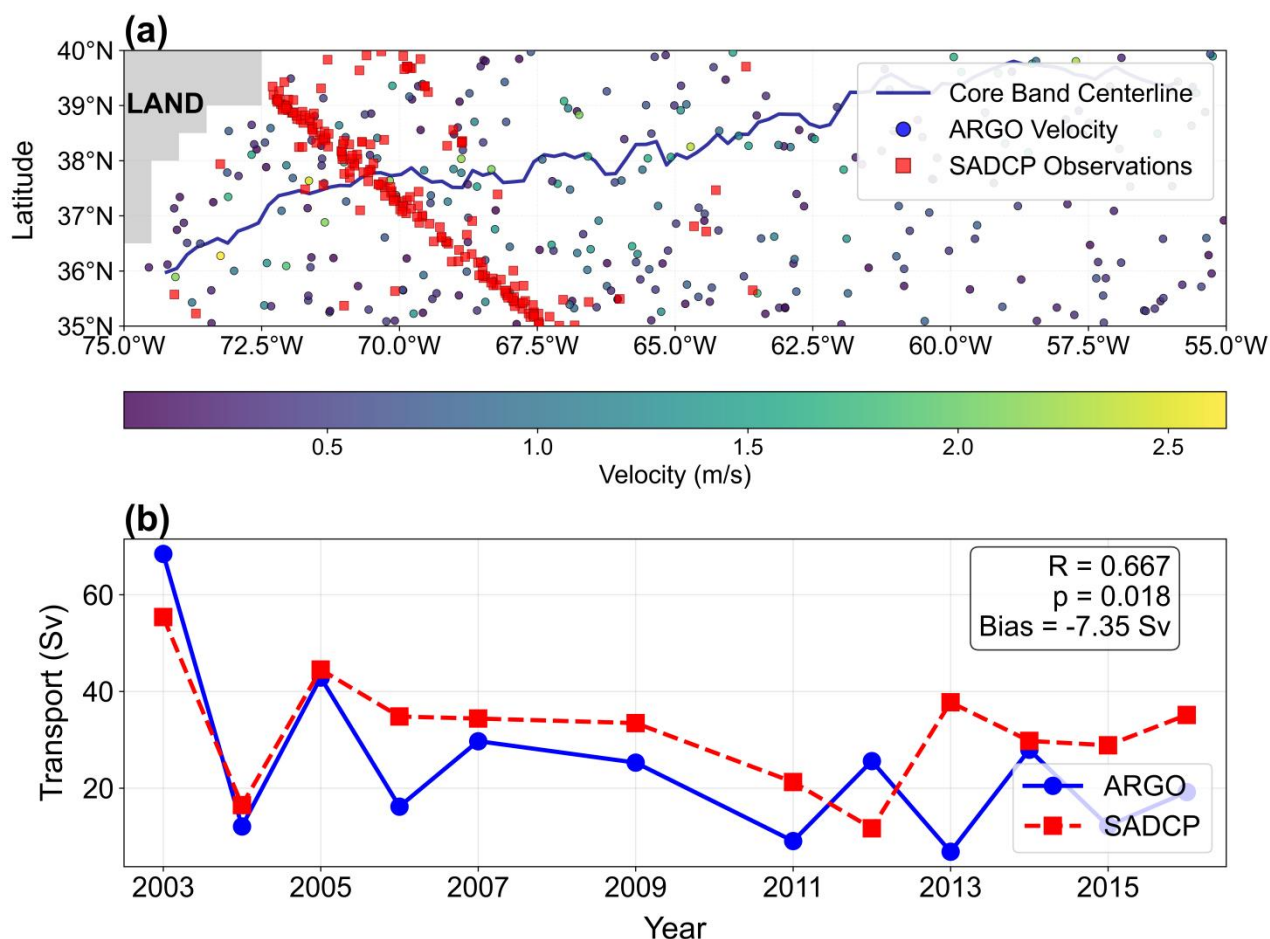




Figure 7. Validation of Argo-based transport estimates. (a) Spatial distribution of observations; (b) Annual transport time series from Argo and SADCP along the section from (35°N, 66.7°W) to (40°N, 73.5°W). Only years with ≥ 6 months of SADCP observations are shown ($n=12$).

4 Discussion

4.1 Interpretation of distinct core-peripheral variability

The core band shows no significant linear trend in position, width, or transport over 2003-2024 (Figures S1 – S3). Furthermore, sensitivity tests confirm that these structural and transport trends remain robust across different bandwidth and gradient threshold selections (Tables S1 and S2), while the peripheral component reverses in 2017. The peripheral variability, which ranges over ± 89 Sv in the annual series (Figure 6a), is more than three times the core variability of ± 20 Sv. The partitioning change therefore reflects two distinct processes, one that isolates the core band from the surrounding flow and one that drives the peripheral reversal.

The core band is the high-gradient region of the jet, and the absence of a significant trend in the core band is consistent with its dynamical isolation from the surrounding flow. Along the Oleander line, the velocity maximum remains nearly constant and the transport of the central core is stable over half-year averages (Rossby and Gottlieb, 1998). A potential vorticity front separates the velocity maximum from the recirculation gyres on either side, and the ambient eddy field is too weak to break it down (Rossby and Zhang, 2001). This front is maintained by potential vorticity homogenization beneath the main thermocline (Frolov et al., 2004). The core band is therefore protected from the gyre and eddy variability that the periphery experiences, which explains why its transport does not follow the interannual changes seen in the peripheral region.

The peripheral region is a residual that contains the recirculation gyres of the North Atlantic subtropical gyre (Cessi, 1990), mesoscale eddies, and other non-core processes, and it responds to changes in the surrounding gyre circulation. The subtropical gyre weakened from the mid-2000s to the mid-2010s (Asbjørnsen et al., 2024), and satellite altimetry shows a corresponding weakening of the free-flowing Gulf Stream over the same period (Dong et al., 2026). Because about 64% of Gulf Stream waters recirculate within the gyre (Asbjørnsen, 2025), and because the gyre circulation covaries with Gulf Stream transport (Curry and McCartney, 2001), the gyre weakening reduced the water supplied to the periphery. The subsequent recovery after 2017 occurred within the period of Gulf Stream intensification reported by Dong et al. (2026), and may reflect a rebound of the gyre circulation. The reversal occurred shortly after the 2015–2016 extreme El Niño, a period of anomalously active warm-core ring formation in the region (Perez et al., 2021), adding eddy-driven variability on top of the gyre adjustment. Among the mechanisms considered here, the adjustment of the subtropical recirculation gyre provides the most direct explanation for the timing of the peripheral reversal.



Mesoscale eddies also contribute to the peripheral transport. Satellite-derived eddy momentum fluxes are sufficient to drive the observed increase in Gulf Stream transport after separation from Cape Hatteras, as well as the formation of the recirculation gyres (Greatbatch et al., 2010). Over 50% of the northern recirculation transport is directly eddy-driven, and eddies strongly reinforce the eastward jet (Zhai et al., 2004). These recirculation gyres are part of the peripheral region, so the eddy-driven transport they carry is included in the peripheral component. The eddy field therefore contributes to the peripheral fluctuations on the same interannual timescales as the gyre circulation.

This asymmetry explains why the fixed-latitude total behaves as it does. A fixed section records the sum of a core without a significant trend and a variable periphery, so the recorded trend depends on the sampling period and on how much of the periphery the section includes. The same physical system can appear to weaken, strengthen, or remain stable depending on the cross-stream extent that an observing system samples. The divergence among existing transport estimates (Piecuch and Beal, 2023; Volkov et al., 2024, 2025; Rossby et al., 2019) follows from this. Separating the two components yields a core transport that is not sensitive to sampling extent, and identifies what each observing system actually measures.

4.2 Limitations and Uncertainties

This study has several limitations. Deep drift estimates from Argo trajectories may contain errors. The Park model extrapolation error may be amplified in the Gulf Stream core, affecting transport estimate accuracy. Hernández-Guerra et al. (2010) similarly noted that representativeness error in Argo velocities is a major source of uncertainty when using Argo data to study the AMOC.

A second limitation is the record length. The 22-year record is adequate for interannual variability but too short to distinguish it from long-term trends. SADCP coverage ends in 2018, so validation is limited to 2003–2018. Therefore, the trends reported here should be interpreted as decadal-scale features rather than multidecadal trends. Argo absolute transport estimates carry a systematic bias, but the relative changes and interannual patterns are robust.

The physical components of peripheral transport are complex, comprising contributions from recirculation gyres, mesoscale eddies, and other non-core band processes. Their relative contributions remain unquantified. The partition between the core without a significant trend and the variable periphery is identified from the velocity field rather than from an explicit separation of these processes.

5 Conclusions

Long-term Gulf Stream transport estimates diverge because existing observing systems sample different cross-stream extents. Using Argo float trajectories from 2003 to 2024, we developed a Core-Peripheral Transport Decomposition Method that separates the core band without a significant trend from the variable periphery.



The two components evolve in distinct ways. Core-band transport shows no significant trend throughout, while peripheral transport declines at -4.99 Sv yr^{-1} before 2017 ($p = 0.004$) and recovers at $+20.01 \text{ Sv yr}^{-1}$ afterward ($p = 0.041$). The core fraction of the fixed-latitude total rises from approximately 33% to more than 100% in 2015 and 2019, before decreasing toward 26% at the end of the record.

Because the core shows no significant trend and the periphery reverses, the trend recorded at a fixed section depends on the sampling period and on how much of the periphery the section includes. This explains why long-term transport estimates from different observing systems diverge. Distinguishing the two components resolves the apparent disagreement and provides a common basis for comparing transport estimates across observing systems. The framework is applicable to other boundary currents with strong lateral structure, and provides a basis for designing cross-stream sampling strategies in future observing systems.

Code and data availability

Argo float trajectory data are publicly available from the International Argo Program (<https://argo.ucsd.edu>; <https://doi.org/10.17882/42182>). GEBCO bathymetry data are available from the GEBCO project (<https://www.gebco.net/>). SADCP data are provided by the University of Hawaii Sea Level Center (<https://uhslc.soest.hawaii.edu>).

Author contributions

T.L. and Y.C. contributed equally. T.L. designed the study, performed the analysis, and wrote the manuscript. Y.C. curated the data and validated the results. S.A. supervised the project and acquired funding. F.L. contributed to data interpretation and manuscript revision. M.P. contributed to data interpretation and manuscript revision.

Competing interests

The authors declare that they have no conflict of interest.

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Supplement

The supplement related to this article is available online.

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