A four-year time series of Antarctic Circumpolar Current transport through Drake Passage from moored observations

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Heterogeneity
Barotropic-baroclinic partitioning changes over short distances [Smith et al., 2010; Pena-Molino et al., 2014; Rintoul et al., 2014]
cDrake -- Drake Passage
Dynamics and Transport of the ACC

- Local dynamics array
- Transport line – C-line

\[ \bigtriangleup \bigtriangleup = \text{CPIES} \]

\[ \bullet = \text{short current meter mooring} \]

4 years, 12/2007 - 12/2011

co-PI's: T. Chereskin, K. Donohue, R. Watts
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CPIES:
current and pressure recording
inverted echo sounder

Measures currents 50 m off bottom.

Measures round trip travel times of acoustic pulses from bottom to surface.

Measures bottom pressure.

CPIES array yields daily maps of current and temperature and buoyancy fields $u(x,y,p,t)$, $T(x,y,p,t)$, $b(x,y,p,t)$

Donohue et al. (2010);
Firing et al. (2014)
Terminology/Methodology

ocean current = baroclinic shear plus bottom reference.

Absolute geostrophic currents are the vector sum:

\[ \phi = \phi_+ - \phi_- + u_{\text{ref}} + u_{\text{bcb}} \]

\[ \mathbf{u} = \mathbf{u}_{\text{bcb}} + \mathbf{u}_{\text{ref}} \]

\( \phi \): geopotential stream function;
\( u_{\text{bcb}} \): baroclinic shear, zero at the bottom;
\( u_{\text{ref}} \): reference or barotropic current measured at bottom.
Standard error ellipses are small compared to the record-length mean near-bottom currents.

Mean near-bottom currents are not aligned with SSH contours except along the northern boundary where both the SAF and near-bottom currents flow parallel to the continental slope.

Strong near-bottom flow in the central passage where deep cyclogenesis occurs repeatedly occurs when ACC meanders develop in concert with deep eddy formation [Chereskin et al., 2009].

South of 60°S the currents in the deep passage are weaker, typically less than 6 cm/s.

Along the C-line, a bottom reference velocity of zero is not appropriate -- high horizontal resolution is required to determine the mean BT transport.
Currents rotated to coordinate system along and across the C-line.

The along-passage annual means are remarkably stable from year to year across the whole Passage and agree well with the four-year averages.

We use all available deep current measurements with record lengths greater than one year to resolve the structure of the BT current across the C-line.
Currents rotated to coordinate system along and across the C-line.

**Method**

- Trapezoidal integration of the near-bottom mean current multiplied by the site-dependent water depth.

- Near steep topography, the integration was distance-weighted to account for variations in spatial correlation length scales.

- Careful analysis of methodological errors include resolution and possible bottom trapping.
South of 60°S, the mean transport is weak and slightly westward.

Eastward transport accumulates northward across the passage beneath the SAF and PF.

Slight transport decrease between the two fronts is associated with the cyclonic flow that recirculates in the Yaghan Basin [Chereskin et al., 2009; Ferrari et al., 2012].

Mean BT transport is 43.8 Sv with an uncertainty of 9.5 Sv.

Distributed uniformly across the passage, this mean transport corresponds to an eastward bottom reference velocity of 1.3 cm/s.
Error Estimates

Array-wide resolution for 90-day low passed currents: 9 Sv

Correlation scales near topography
  Shackleton Fracture Zone: 2.8 Sv
  South Shetland Trench: 1.8 Sv

Possible bottom trapping bias: -4+/3 Sv

Total Error: 9.5 Sv
Bottom pressure anomaly differences provide estimates of the barotropic transport variability.

*The northern-slope region uses near-bottom currents*
Total Transport

Mean: Baroclinic component is 127.7 Sv -- accounts for 75% of the total eastward transport of 171.4 Sv.

Variability: Barotropic component standard deviation is 18.3 Sv and accounts for 80% of the total variability.

Full-depth baroclinic transport referenced to zero at the bottom Chidichimo et al. [2014].
Total Transport

BC: fluctuations with periods less than 60 days days account for 65% of the variance.

BT: fluctuations with periods 20-180 days account for 50% of the variance.
cDrake: 171.4+/11 Sv.

> 20% higher than the canonical value of 134 Sv [Whitworth et al., 1982].

Cunningham et al. [2003]'s revision
--maximum transport of 161 Sv
--good agreement with the cDrake minimum of 160 Sv.

ISOS mean estimate: three hydrographic surveys with the current meter moorings.

Two critical moorings were lost in northern Drake Passage between the SAF and PF – a region that in cDrake contributes substantial BT transport.
cDrake: 171.4+/ 11 Sv.

? really such a big number?

SADCP 2004—2009: total transport in the upper 1000 m 95 ± 2 Sv.

cDrake: BT+BC upper 1000 88 ± 5 Sv,

--good agreement with the direct estimates.

[Firing et al., 2011]
cDrake: 171.4+/ 11 Sv.
? really such a big number?

Koenig et al. [2014] combine current meter mooring data and altimetry.

Latitude-dependent empirical look-up between the surface velocity and the depth-dependent velocity structure from moored current meters along a Jason track.
cDrake: 171.4+/ 11 Sv.

? really such a big number?

Koenig et al. [2014]:
total: 141 sem 2.7 Sv
bc: 136 sem 2.7 Sv
bt: 5 sem 4 Sv

Our total transport estimates are higher, mainly due to the strong cDrake BT contribution.
Because the spacing of the Koenig et al. [2014] moorings do not resolve the ACC structure, their methodology relies on the meandering surface currents to effectively provide the necessary horizontal resolution.
cDrake Transport

• A moored array measured bottom currents across Drake Passage with unprecedented spatial and temporal resolution.

• Annual mean near-bottom currents are remarkably stable from year to year over the four-year record.

• The mean barotropic ACC transport is 43.8 Sv ± 9.5 Sv.

• This latest estimate of 171.4 Sv is over 20% larger than the canonical value of 134 Sv measured nearly 40 years ago.

• Transport variability barotropic/baroclinic contribution – 80/20%.

cDrake measurements now assimilated into SOSE – should help put measurements in regional context.
Error Estimates

Distance weighted trapezoidal integration with \( l = 24 \) for C16.

Error estimation based on \( l = 24 \) km (distance from the South Shetland Trench) with \( l = 36 \) km (no distance weighting).
Error Estimates

Correlation scales near topography

Distance-weighted trapezoidal integration with $l = 15$ km for H01 and H03.

Error estimation allowed $l$ (distance from the SFZ) to vary between 10, 15, 20 km based on LADCP from c-Drake and Koshlyakov et al. 2012.
Complex ridge and seamount structures are:
- hot spots of cross-frontal exchange [Thompson and Sallee 2012]
- regions where the BC/BT partitioning changes over short distances [Smith et al., 2010; Pena-Molino et al., 2014; Rintoul et al., 2014]

These findings place strong demands upon the community to resolve the spatial and temporal structure of the ACC both numerically and observationally.

The ACC’s vertical and horizontal structure is intimately linked to:
- mechanisms that transport mass, heat and other properties across the SO
- where/how the ACC responds to atmospheric forcing [e.g. Thompson and Naveira-Garabato 2014].
Accurate ACC transport estimates are required to assess how the Southern Ocean is responding to climate change.

Challenges:

**Bias**
- Basin-wide transport calculations are often constrained by zero or near-zero mass flux conditions a requirement that can not be applied to the ACC.
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- In ACC – topography responsible for along-path heterogeneity.
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Standard deviation of total barotropic transport is 18.3 Sv.

Transport fluctuations with periods 20-180 days account for 50% of the variance.