State, variability and climatic drivers of Southern Ocean CO$_2$ sink (especially winter conditions)

- multi-pronged approach
- Combine atmospheric and ocean approaches with new surface measurements
- Aim to adequately calibrate surface pH-to-pCO$_2$, estimates from autonomous vehicles

Atmospheric measurements of CO$_2$ (including ships, islands)

Atmospheric inversions

Air-sea ΔpCO$_2$ ships and ASVs

Assessment of ΔpCO$_2$ interpolation

Ocean inversions

Surface pH

SOCCOM and UK biogeochemistry floats

**Note:**
- **Glider**
- **Surface pH**
Using existing and future observations, e.g. from different platforms, applying different mapping techniques and do Observational System Sampling Experiments (OSSEs)

Using OSSEs in 4 dimensions, to
- assess present uncertainty
- determine optimum network of observations
- to reduce uncertainty in the future

Bakker et al., 2016; Gruber et al., 2009; Landschützer et al., 2015; Lenton et al., 2013; Majkut et al., 2014; Schuster et al., 2016
Erroneously elevated pCO$_2$ reduces uptake
Erroneously elevated pCO$_2$ reduces uptake.

The dominant effect is over the ACC, not the Antarctic shelf.

Simple model simulations:
- Test UKESM ensemble against CFC and/or $^{14}$C data
- Assess impact on present/future CO$_2$ uptake

Paul Halloran + Kevin Oliver
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The ocean transient tracers, CFCs and $\text{SF}_6$

’Tracing the pathways climate anomalies follow as they enter and move through the ocean’, Jenkins (1996)

• State of the art instrumentation

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Anthropogenic passive tracers with time-dependent source functions

• Visualisation and dating of water masses
• Time scales and dynamics of the ocean ventilation
• Anthropogenic $\text{CO}_2$ and heat ocean uptake
• Biogeochemical rates as apparent oxygen utilisation rates
• Ocean model development

Distributions of CFC-12 and $\text{SF}_6$ from the Weddell Sea to South Georgia during the Dimes cruise JR281 in Mar-Apr 2013.

Observations will substantiate our understanding of the ocean circulation & biogeochemistry and record change.
Anthropogenic and natural ocean carbon uptake

- Analysis of the oceanic carbon cycle (observations, ESM)

- Anthropogenic carbon inferred from CFCs and SF₆ using the TTD methodology at 24.5° N Atlantic

- Decomposition (Williams 2011) of the total carbon ($C_{\text{tot}}$, $C_{\text{sat}}$, $C_{\text{carb}}$, $C_{\text{soft}}$, $C_{\text{res}}$, $C_{\text{dis}}$, $C_{\text{ant}}$) to tackle the physical and biological pumps

- Analysis expansion over time and space to include ESM and GCM outputs

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Far-field controls on $\mathrm{CO}_2$ flux over the ACC

A theoretical scaling, which predicts the relationship between Atlantic and overturning in models (right), can be used to understand the far-field effect of AMOC changes, significant on a centennial timescale (below).

This can also be used to determine far-field effects of S.O. changes (e.g. on the N. Atlantic sink).
We will use dating of transects across the Pleistocene Patagonian Icesheet to reconstruct migration of the Westerlies.

This is the only terrestrial record that can be used in the mid-latitudes of the SH as other palaeoenvironmental data are not available.
Role of the S. Ocean in global climate dynamics:
Biases linked to cross-equatorial energy transport, monsoons and persistent ‘double ITZC’ biases in climate models

Hawcroft et al., 2016 in press