Net community production in the Southern Ocean

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Collaborators/hosts: Bronte Tilbrook (CSIRO, Hobart) and French/Australian Astrolabe time series study; Pedro Monteiro, CSIR, Cape Town, and SA Agulhas time series study; SAZ/SENSE process study; Bonus/Goodhope process study; Roberta Hamme and Southern Ocean GasEx process study

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Definition and premise

- NCP is the rate of O_2 or C_{org} production by photosynthesis - consumption by respiration (and photooxidation)
- Domain is euphotic zone or mixed layer; not that different in Southern Ocean
- C_{org} storage is modest, therefore NCP = POC export + DOC export

Outline

1. Seasonal/annual NCP estimates for the entire basin (~ 2 mol m^{-2} yr^{-1} or 20 mmol m^{-2} day^{-1} for 100 day growing season)
2. Methods for constraining local NCP
3. Seasonal variations in NCP
4. Spatial variations in NCP; implications for controlling factors
5. Prospects for scaling NCP
6. Questions/suggestions

1. Basin-scale estimates of Southern Ocean NCP

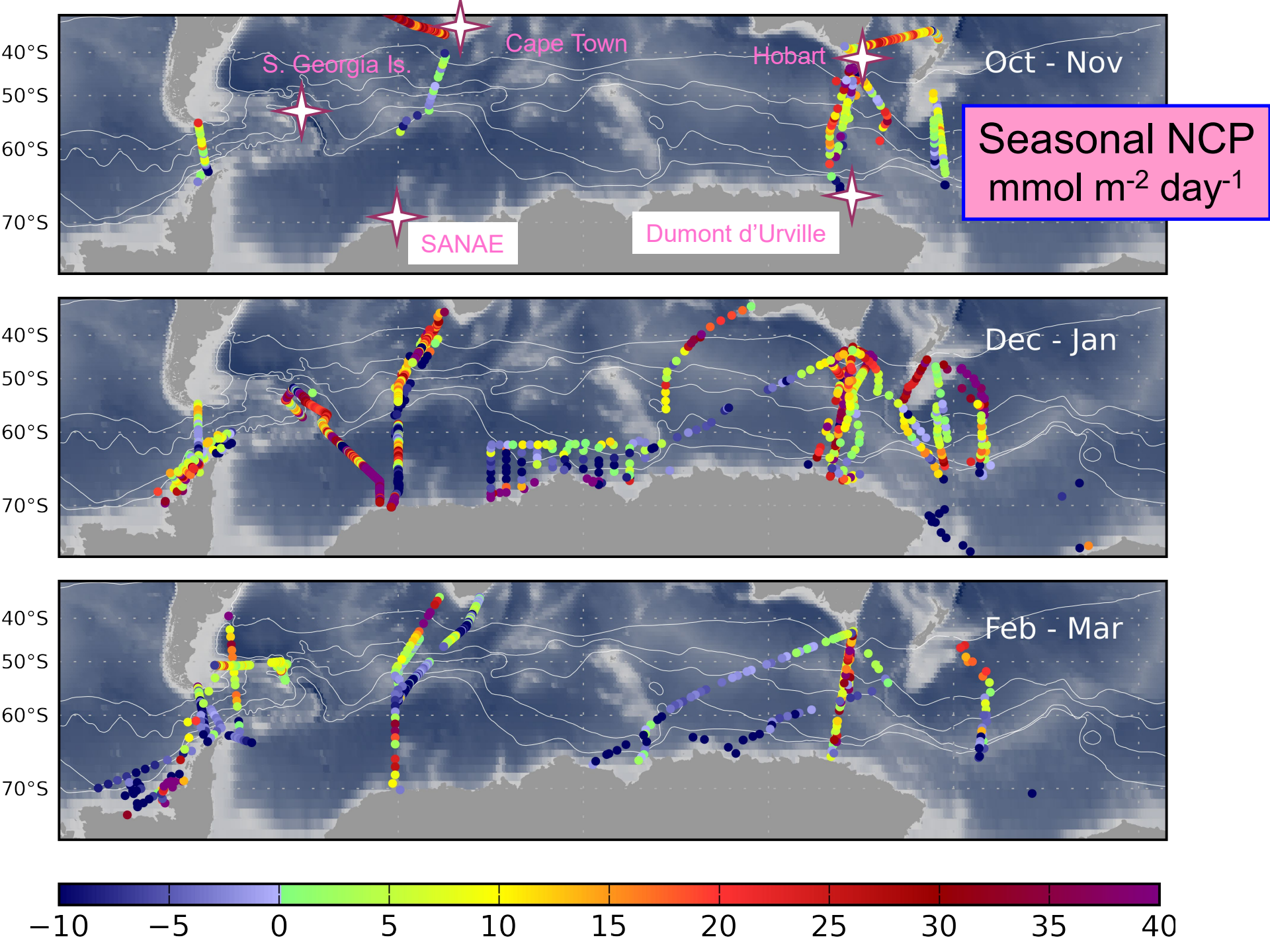
- Morrison et al. (2001) Seasonal nutrient drawdown along 170˚ W: 1.5-2.2 moles m^{-2} $year^{-1}$
- Lourey and Trull (2001) Seasonal nutrient drawdown S of Australia: SAZ, ~ 3; PFZ ~ 1.5 moles m^{-2} $year^{-1}$
- DiFiore et al. (2006) Seasonal nitrate drawdown using $\delta^{15}NO_3^-$ change to account for advection, in SAZ: 3 moles m^{-2} $year^{-1}$
- Reuer et al. (2007) Air-sea O_2 fluxes supported by NCP at ~ 500 stations: ~ 2 moles m^{-2} $year^{-1}$
- Pollard et al. (2006), Seasonal upper ocean nutrient drawdown evaluated given Ekman flow: 2.7 moles m^{-2} $year^{-1}$ S of 50˚ S
- Schlitzer (2002), subsurface nutrient additions evaluated using a GCM: ~ 2 moles m^{-2} $year^{-1}$
- Moore et al. (2004) Model euphotic zone NCP in S. Ocean that reproduces seasonal changes in atmopsheric O_2/N_2 ratios: ~ 1.5 moles m^{-2} $year^{-1}$

Nitrate drawdown and recycling of N remineralized below the euphotic zone

- NCP of 2 mol m^{-2} yr^{-1} corresponds to nitrate uptake/export of ~ 1-1.5x10^{13} moles NO_3^-
- NO_3^- upwelled to surface ~ 10 Sv x 30 mmol m^{-3} = 10^{13} moles/year
  - ~ 1/2 of upwelled NO_3^- is lost by subduction
  - Net NO_3^- upwelling ~ 0.5 x 10^{13} moles/year
- Subsurface water supply significant NO_3^- to the euphotic zone
- NO_3^- balance more complicated than simple removal during Ekman drift (Sigman, Sarmiento)

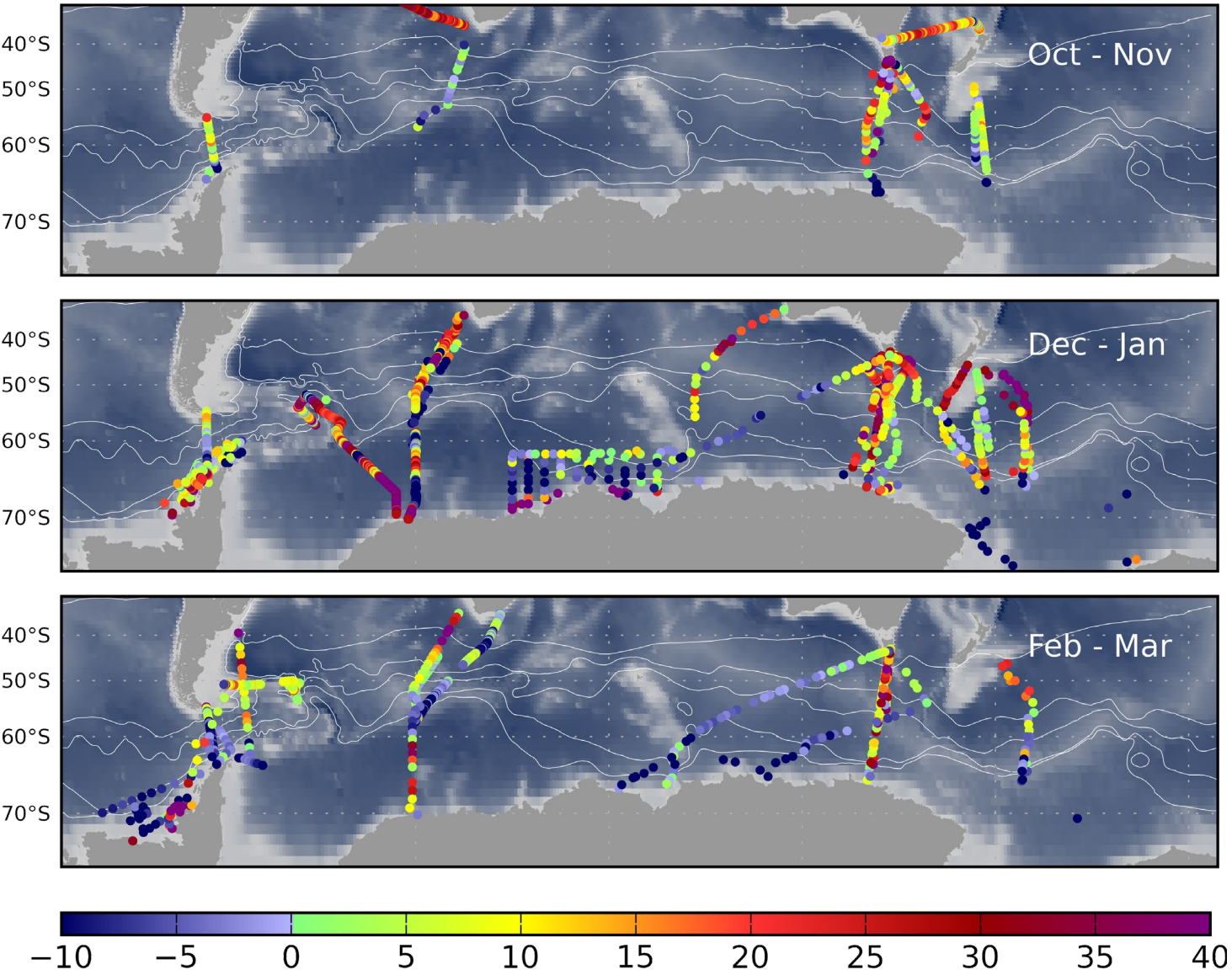
2. Methods for constraining short-term local NCP: the toolkit

- $^{15}NO_3^-$ uptake in incubated samples (accesses 1 day)
- $\Delta[O_2]$ in incubated samples (accesses 1 day)
- ^{234}Th deficiency and $^{234}Th/C$ ratios (accesses last month)
- Shallow sediment traps (accesses last week???)
- Sea surface biological O_2 supersaturation measurements + gas exchange velocity estimate (accesses last ~ 10 days)
  - Upwelling/vertical mixing can introduce O_2-undersaturated waters
  - Gas exchange rate is uncertain
  - Temporal variability is averaged
  - Need to correct for physical supersaturation (Ar)


Seasonal NCP
mmol m-2 day-1
Oct - Nov
Dec - Jan
Feb - Mar
Cape Town
S. Georgia Is.
Hobart
SANAE
Dumont d'Urville
40°S
50°S
60°S
70°S
−10
−5
0
5
10
15
20
25
30
35
40

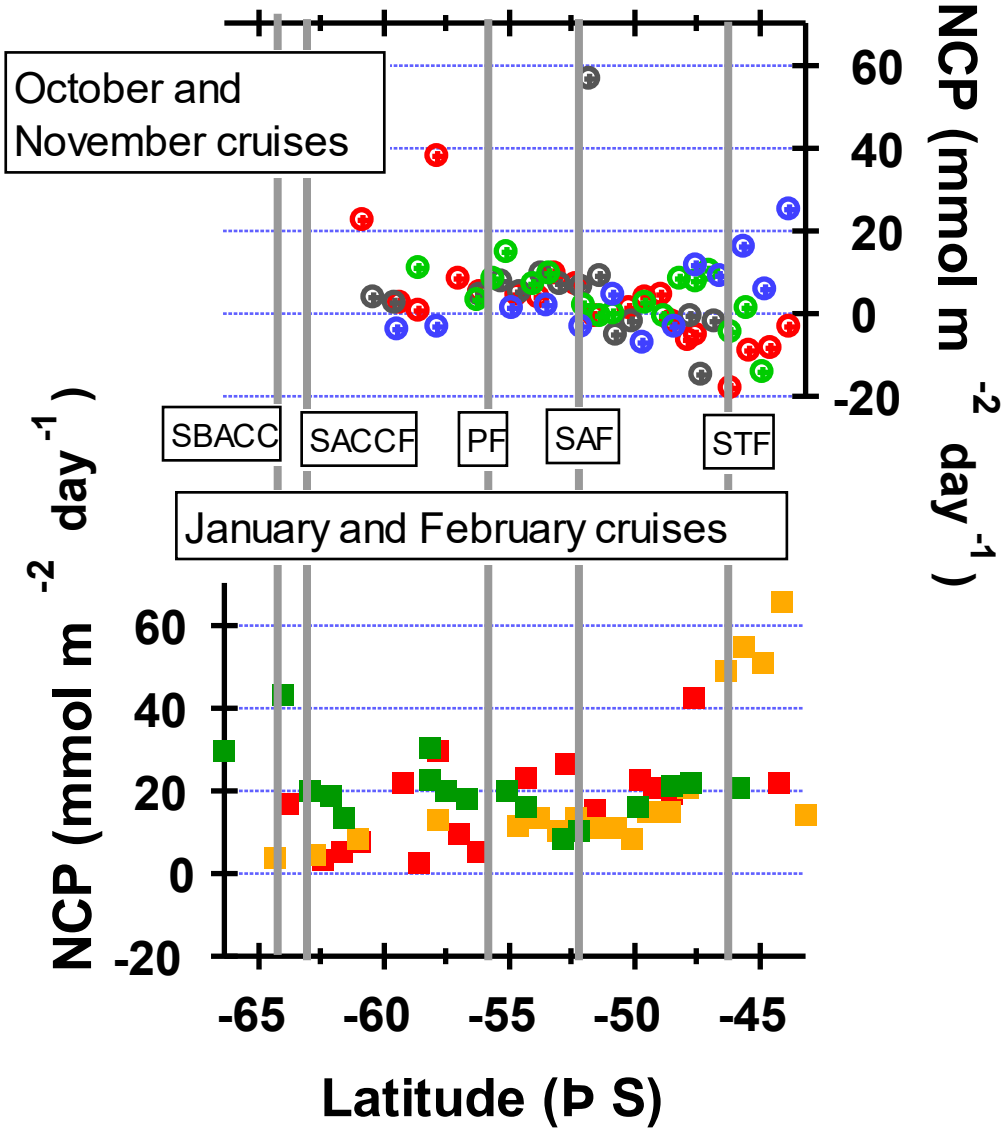
3. Seasonal variations in NCP

- Springtime rates are not exceptional
- End summer/fall rates appear to be lower than Dec./Jan. rates



3. Seasonal variations continued

- Summertime NCP is higher than springtime NCP between Hobart and Dumont d'Urville



3. Seasonal variations continued

- Between New Zealand and Ross Sea, NCP increases from November to December (Tortell and Long, 2009)

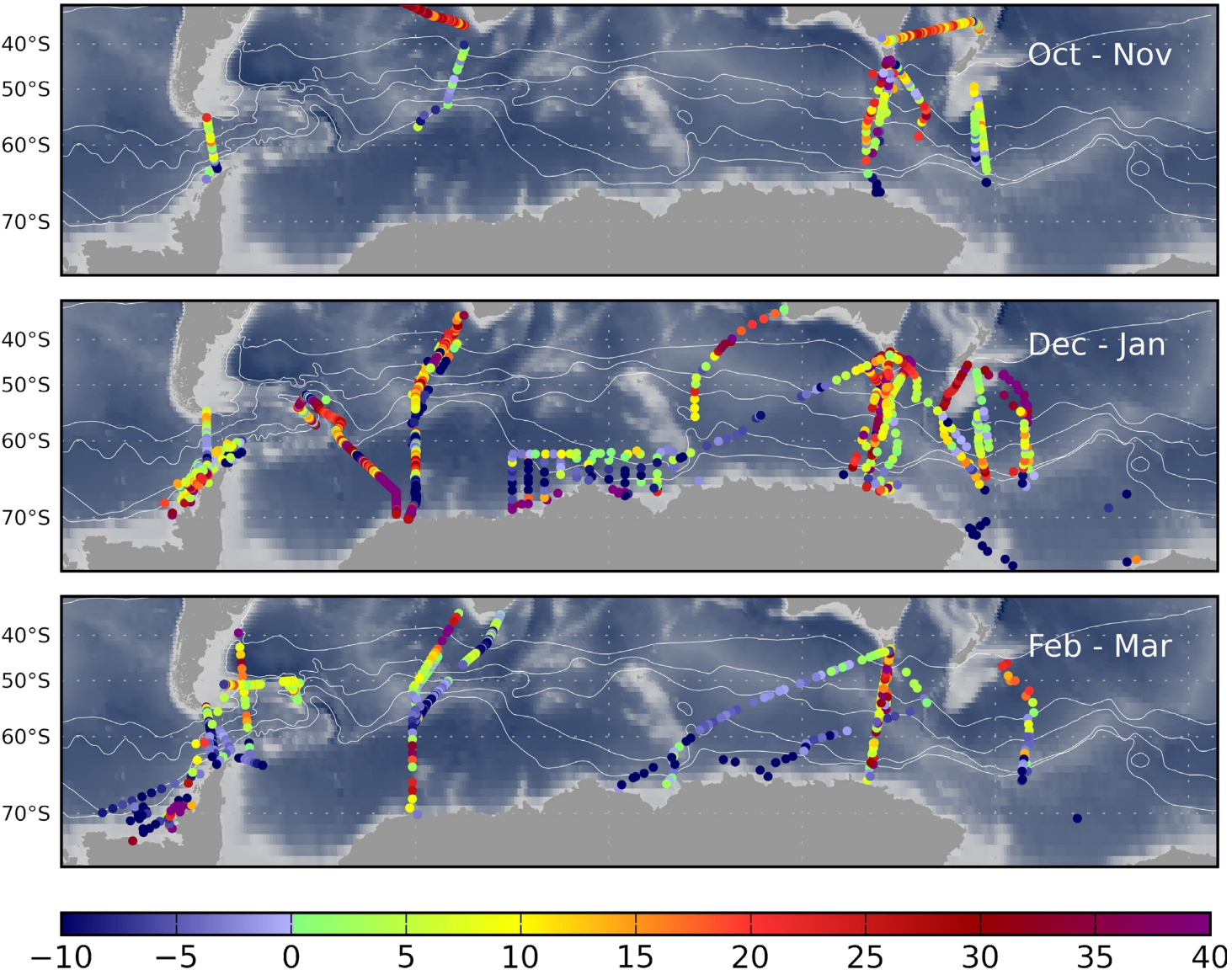
~Dec. 7 ⟶

QuickTime™ and a
decompressor
are needed to see this picture.

↑
~Nov.5

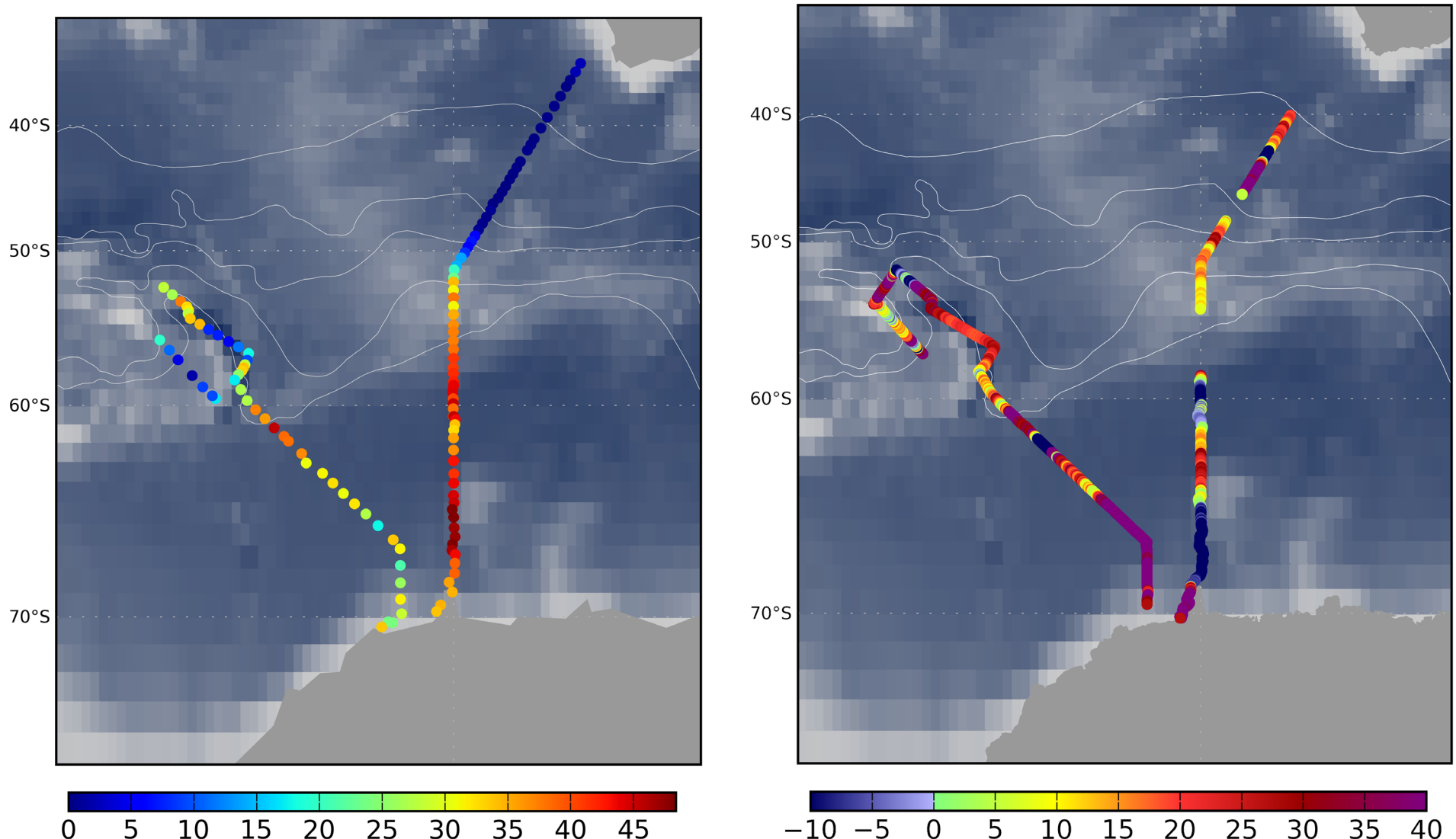
4a. Spatial variations in NCP: role of SiO_2

- Hypothesis: diatoms dominate carbon export/NCP
- Prediction: NCP decreases northward in summer (not validated)



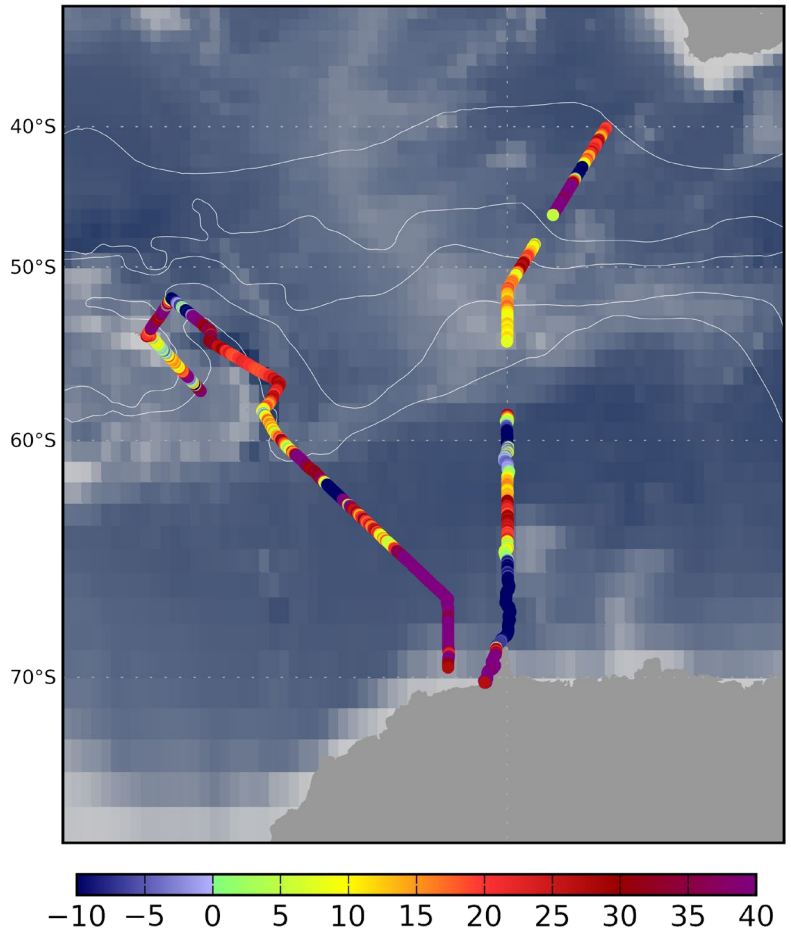
4a. Spatial variations in NCP: role of SiO_2

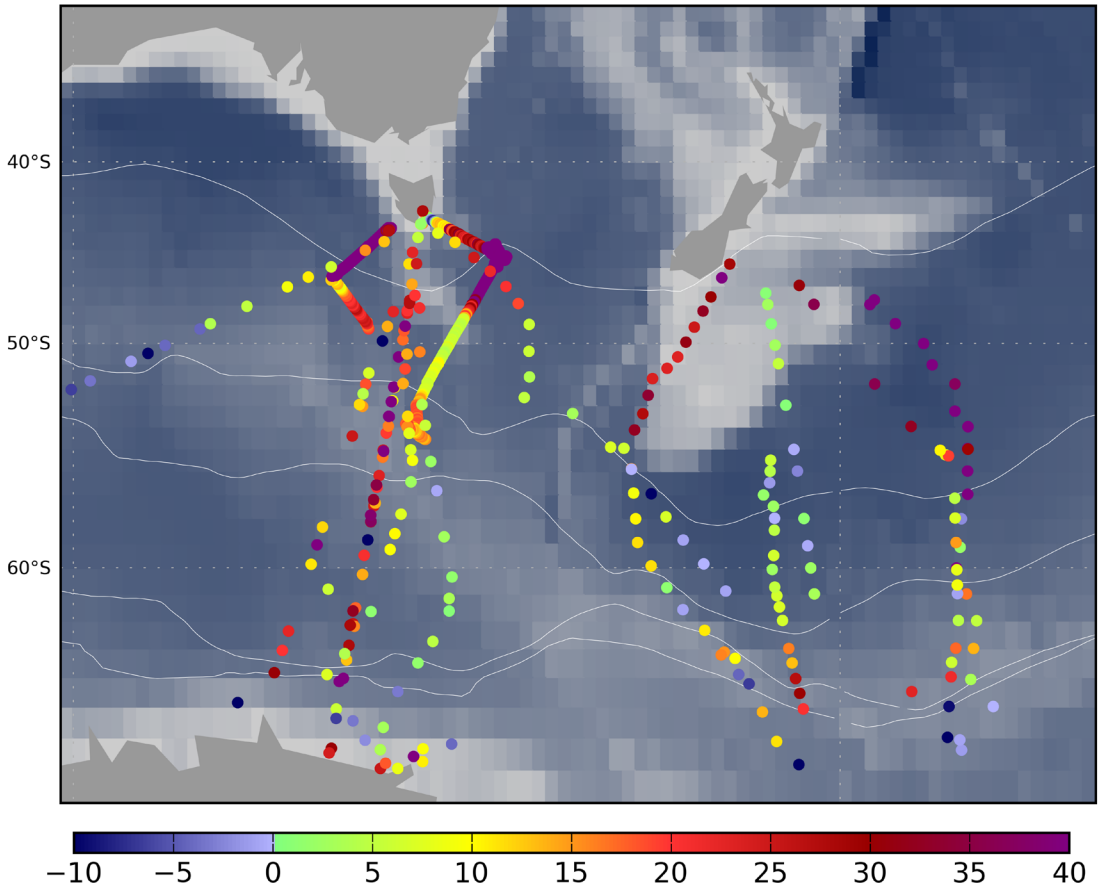
- SiO_2 and NCP from eastern Atlantic (Monteiro and Joubert, CSIR; Cassar)
- Productivity is high north of Polar front, even though SiO_2 is depleted



4b. Spatial variations in NCP: role of bathymetry

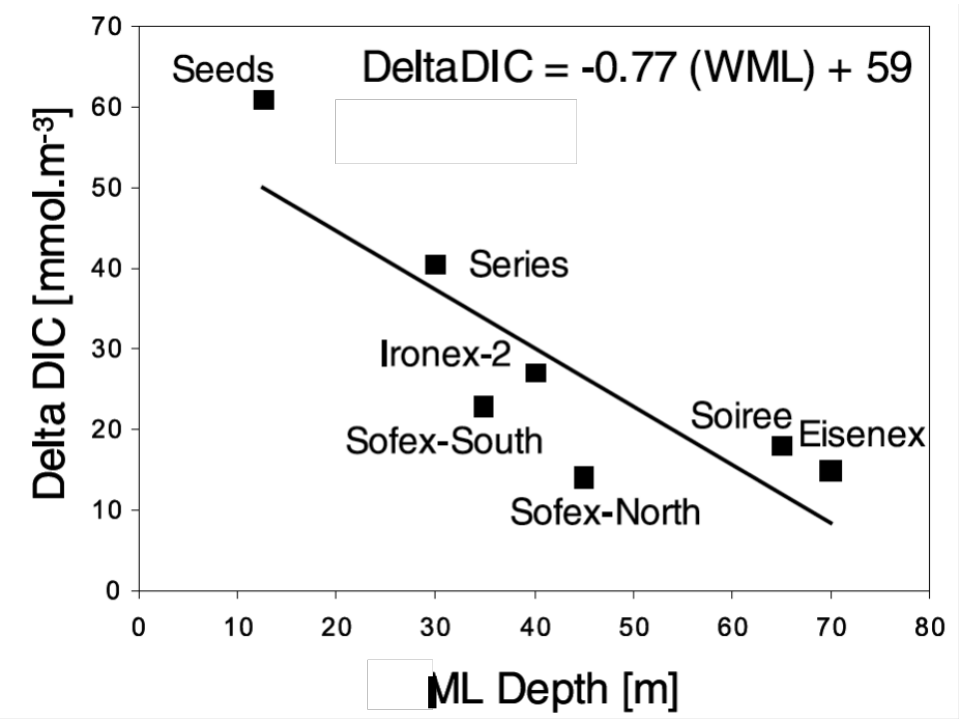
- Flow over topography supplies iron by inducing vertical turbulence,
- Shallow sea floor supplies iron directly



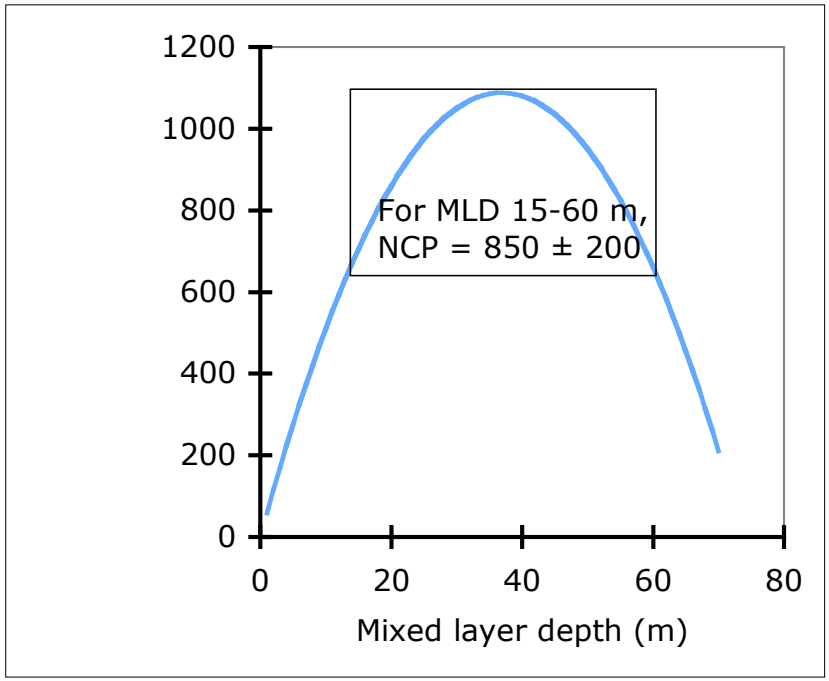


4c. Spatial variations: light limitation

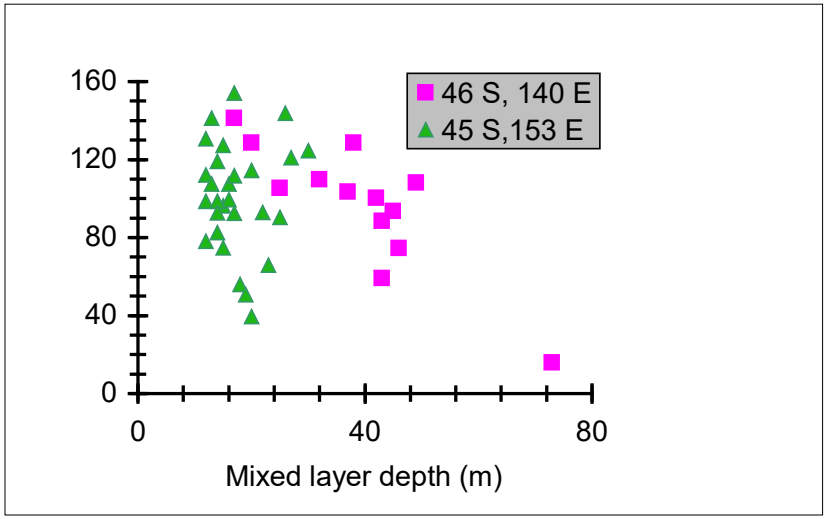
1. Volumetric NCP decreases with z: de Baar



2. Depth-integrated NCP vs. MLD

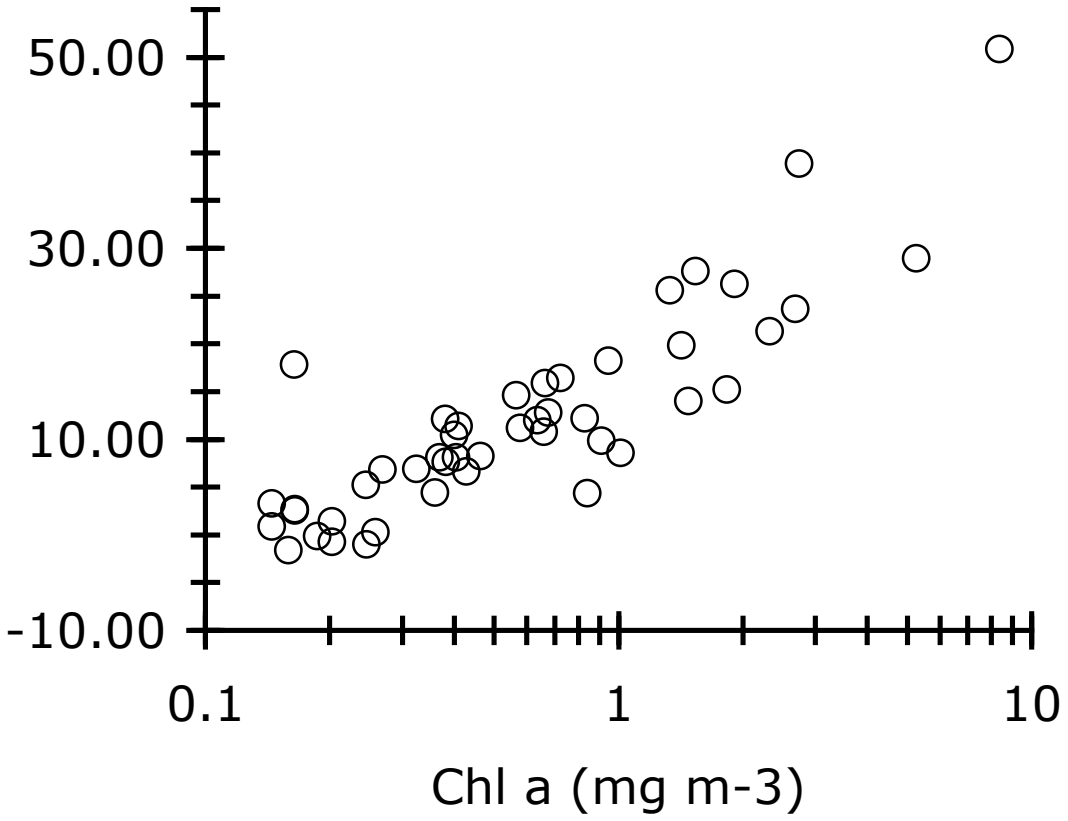


3. SAZ south of Australia: NCP vs. MLD



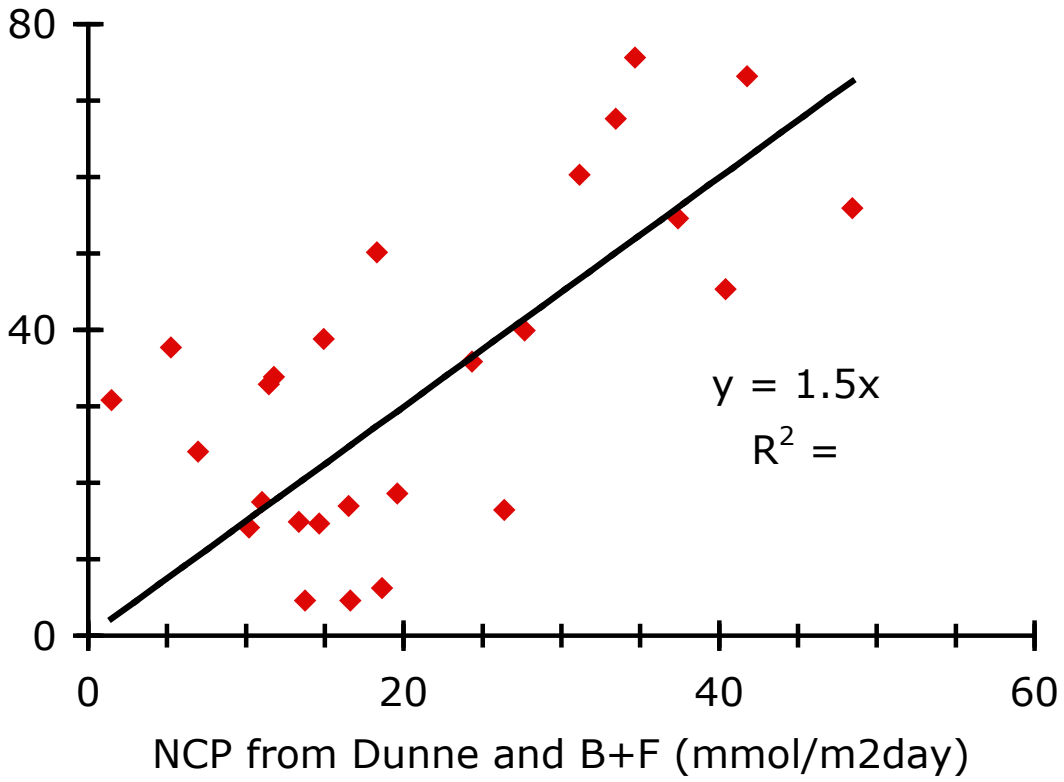
5a. Prospects for scaling: NCP vs. chl off Palmer Peninsula

- Is there a compact relationship between NCP and chl?



5b. Prospects for scaling - one possible strategy

- Start with
  - VGPM (~ ^{14}C production) from B+F: Depends on I, z_{eu}, SST, chl
  - *f* ratio from Dunne et al.: Depends on SST, ln(VGPM/z_{eu})
- Scale VGPM by MLD/euphotic zone depth
- Model NCP = *f* * scaled VGPM
- Compare with observations for SAZ-SENSE

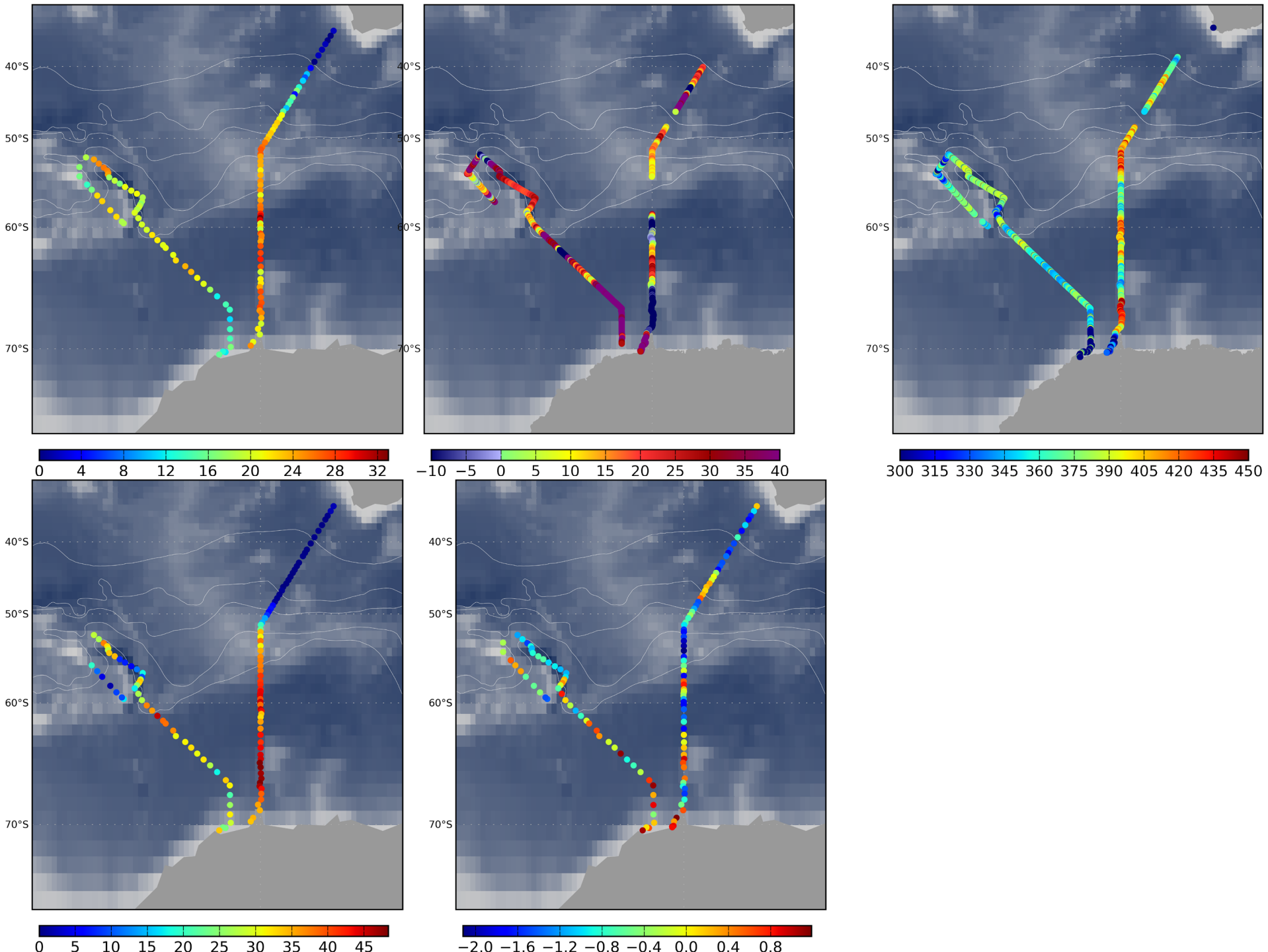


Summary

- Characterization of Southern Ocean NCP is progressing
- Southern Ocean NCP ~ 2 mol m^{-2} $year^{-1}$, similar to other areas
- Temporal variations: somewhat higher in summer, no bloom in W. Pacific
- Spatial variations:
  - NCP highest in north, closest to iron sources
  - SiO_2 not needed for high NCP
  - Evidence for light limitation (SAZ, Palmer Peninsula)
  - Some evidence for NCP changes across bathymetry and/or fronts
- Some hope for scaling NCP from frequently observed properties

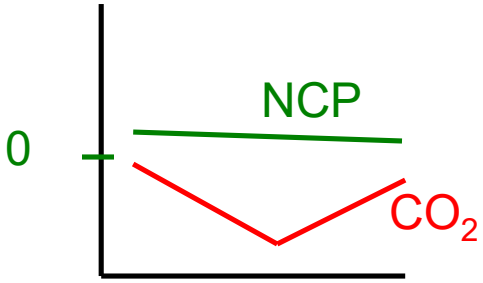
3 questions

- Overall objectives of biogeochemical studies
  - Characterize ecosystems of one of Earth's great domains
  - Understand the present and coming influence of the biota on sea surface pCO_2
  - Understand the influence of the biota on the nutrient burden of subducted AABW, AAIW, and SAMW
- Contributions of experimental biogeochemistry
  - Characterize the autotrophic community
  - Understand the role of heterotrophs in mediating carbon export
  - Understand the remineralization scale length
- Research strategies
  - Autotrophy: ships of opportunity
  - Euphotic zone heterotrophy and remineralization scale length: dedicated process cruises
  - All supplemented by autonomous platforms


40°S
50°S
60°S
70°S
0 4 8 12 16 20 24 28 32
−10 −5 0 5 10 15 20 25 30 35 40
300 315 330 345 360 375 390 405 420 435 450
0 5 10 15 20 25 30 35 40 45
−2.0 −1.6 −1.2 −0.8 −0.4 0.0 0.4 0.8

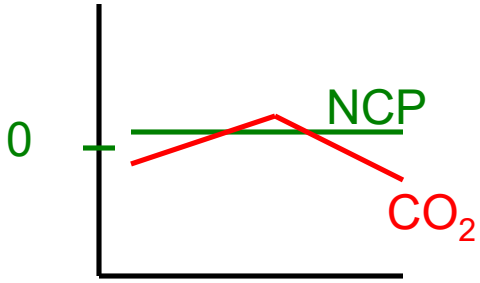
4d: Are there pools of more and less fertile waters?
NCP - PCO_2 relationships, and the history of productivity

a. Productivity is high, then diminishes

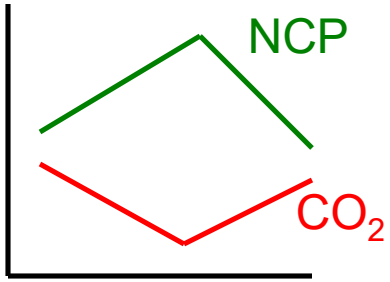


Latitude

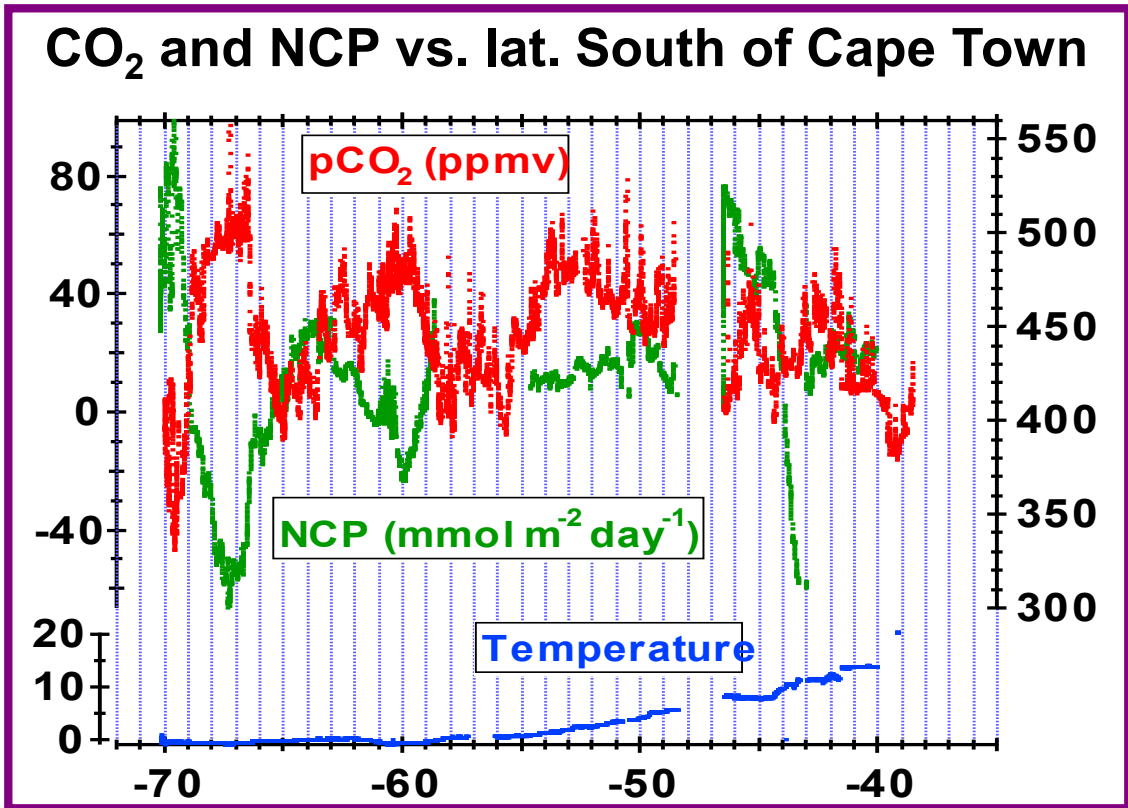
b. Productivity is low throughout growing season



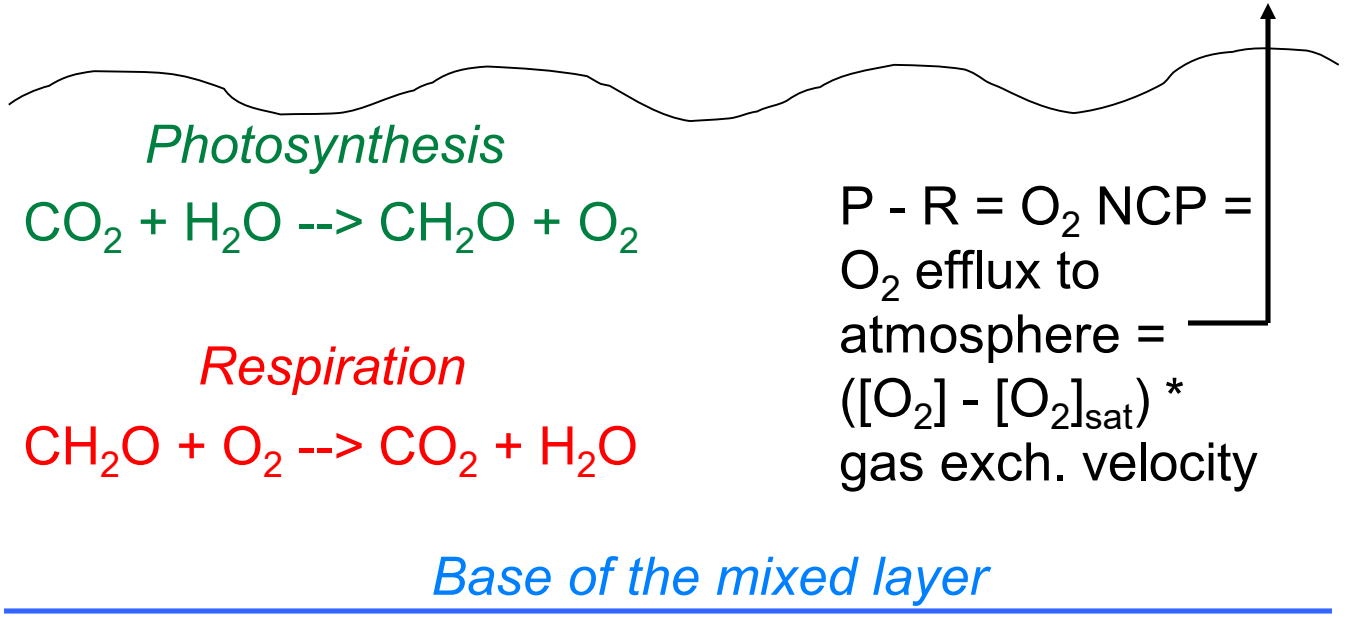
c. Productivity is high throughout growing season



Latitude



Determining net community production in the mixed layer



- Net community O_2 production = flux to atmosphere
- Complication: $[O_2] > [O_2]_{sat}$ because of warming and bubble entrainment
- Measure Ar as inert analog to O_2 to correct for physical supersaturation (Jenkins, Craig, Quay, Emerson, Luz, Stanley, Hamme…)
- O_2/Ar can be measured on samples returned to the lab
- O_2/Ar can be measured continuously using membrane inlet mass spectrometry (Kaiser, Tortell) or equilibrator inlet mass spec (Cassar)