Reorganization of global winds with Abrupt Climate Change and its impact on CO_2

Bob Anderson

With contributions from
Shahla Ali, Louisa Bradtmiller
Simon Nielsen, Martin Fleisher
Brent Anderson and Lloyd Burckle

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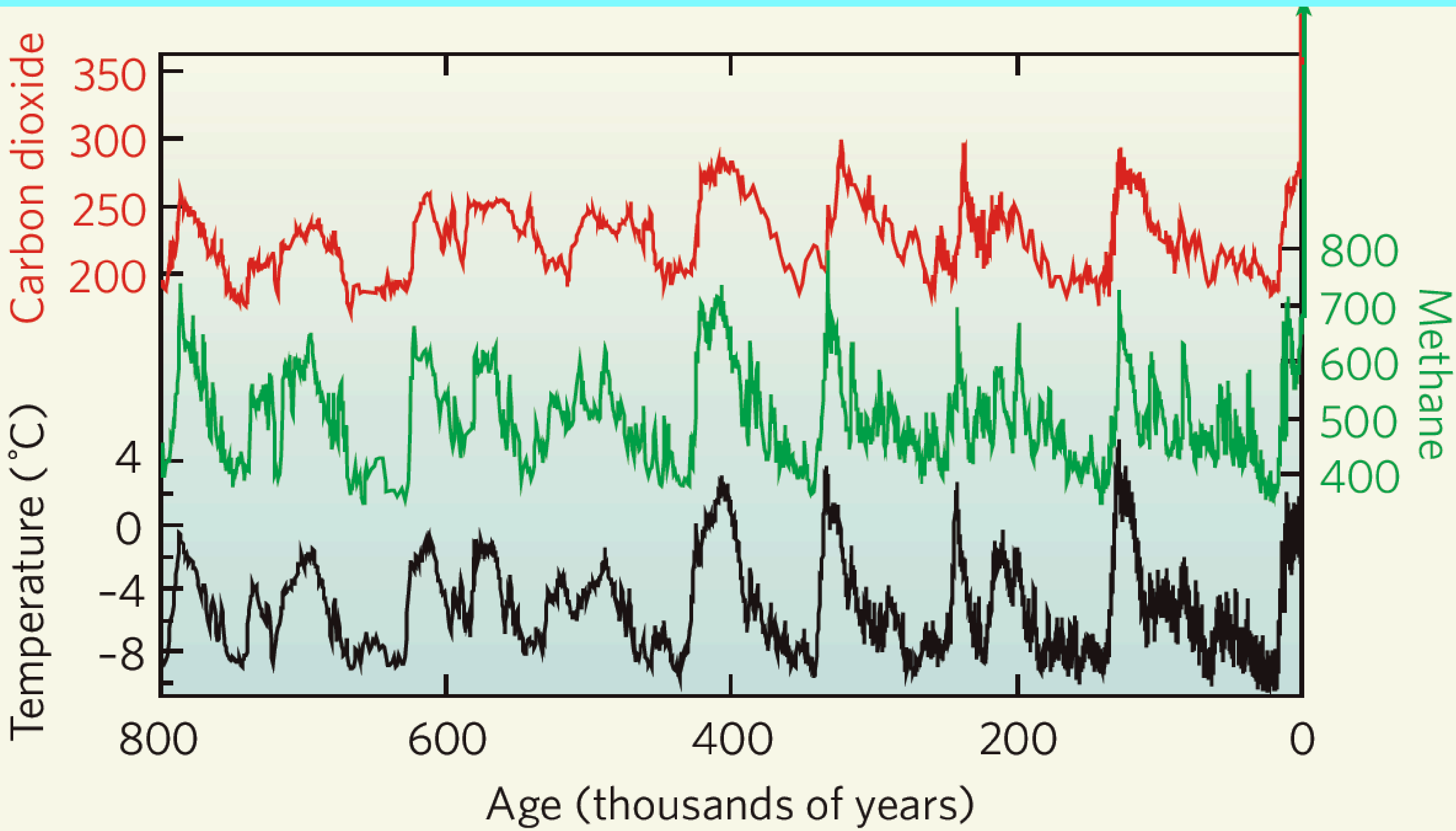
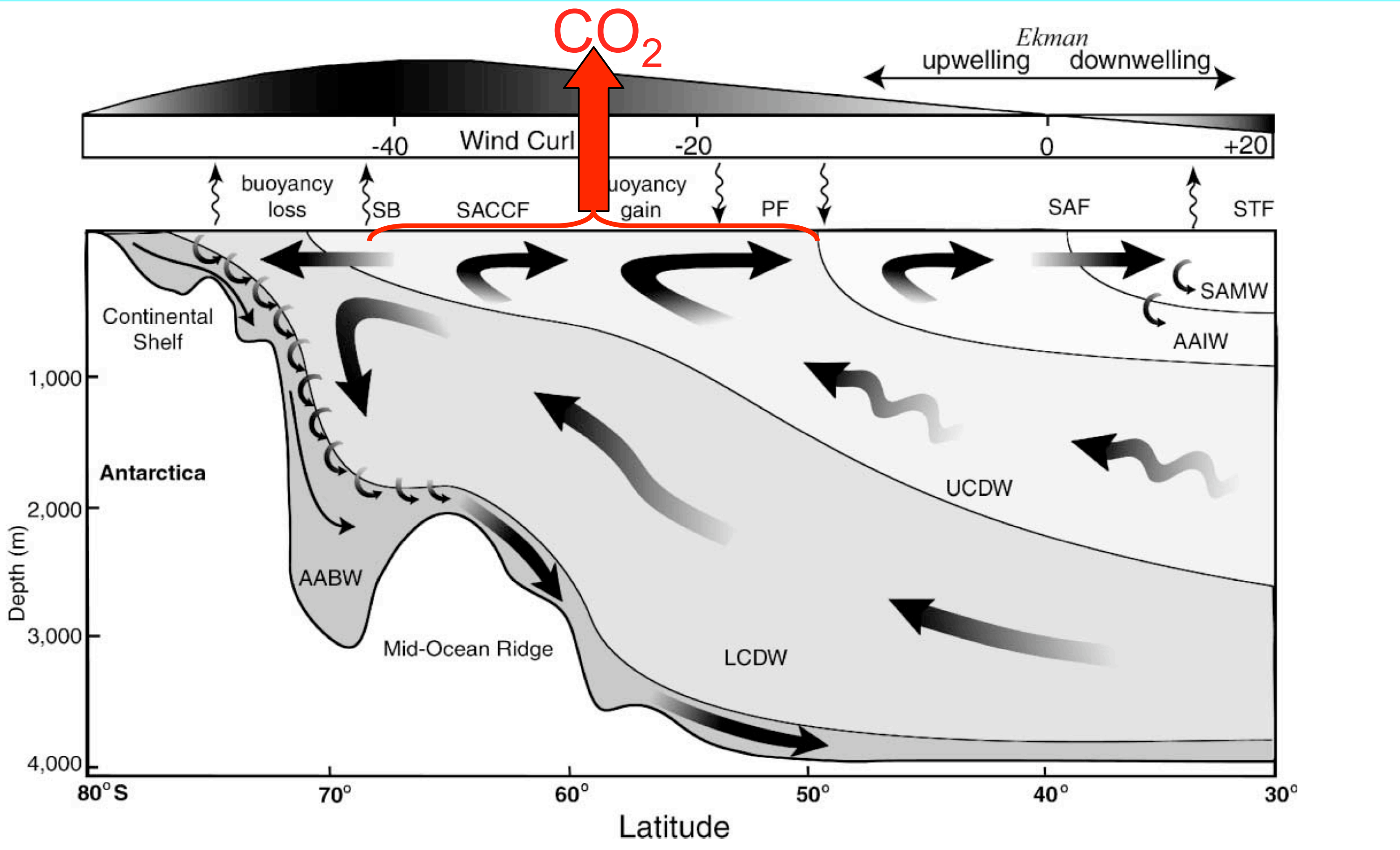
LAMONT-DOHERTY EARTH OBSERVATORY
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

Ice core records show tight coupling between CO_2 and climate



From Brook, 2008

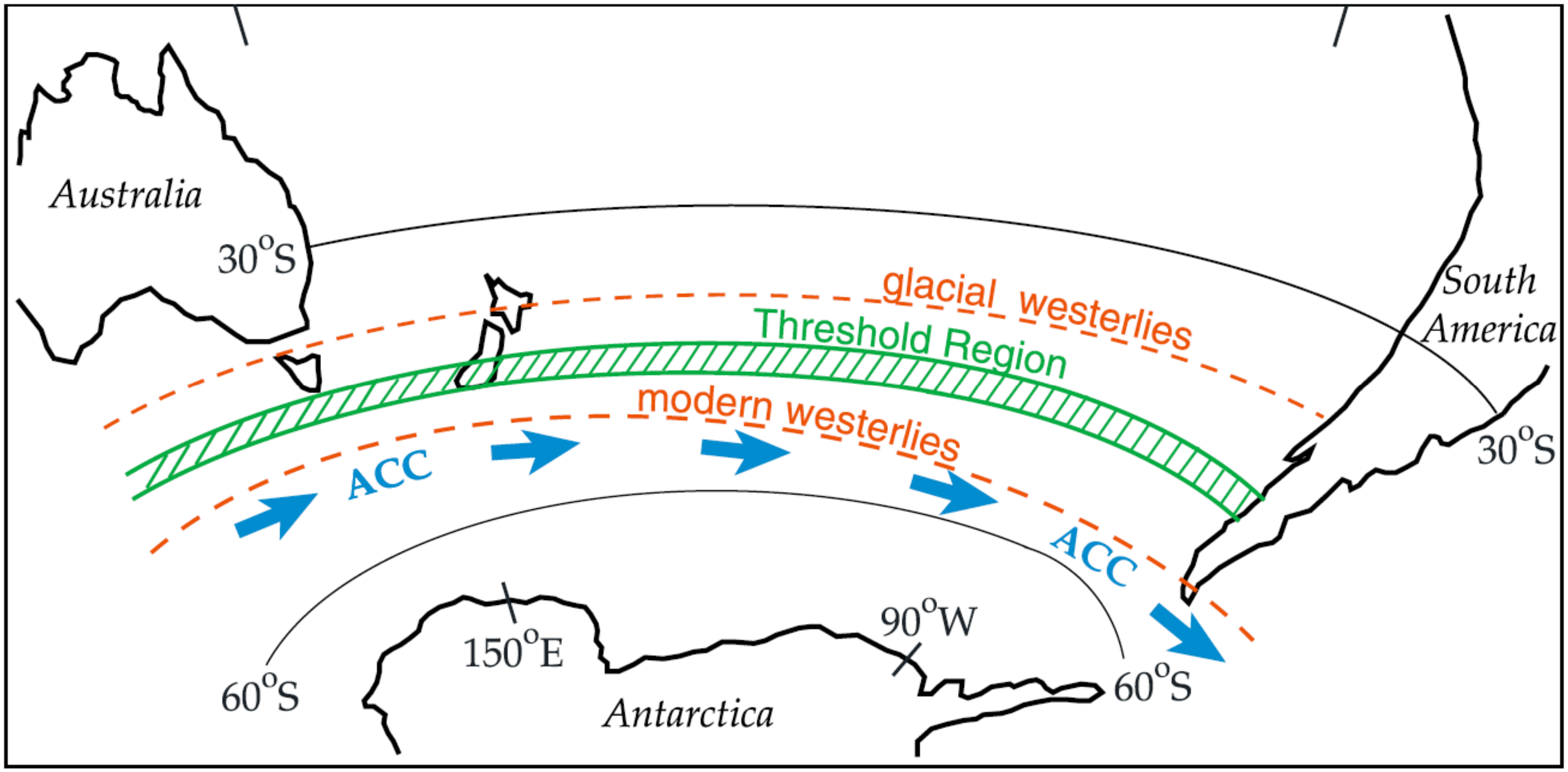
Wind-driven upwelling south of the Zero in Wind Stress Curl “ventilates” deep waters



Upwelling ventilates CO_2-rich deep water masses S of the APF

Figure of K Speer redrawn by T Trull

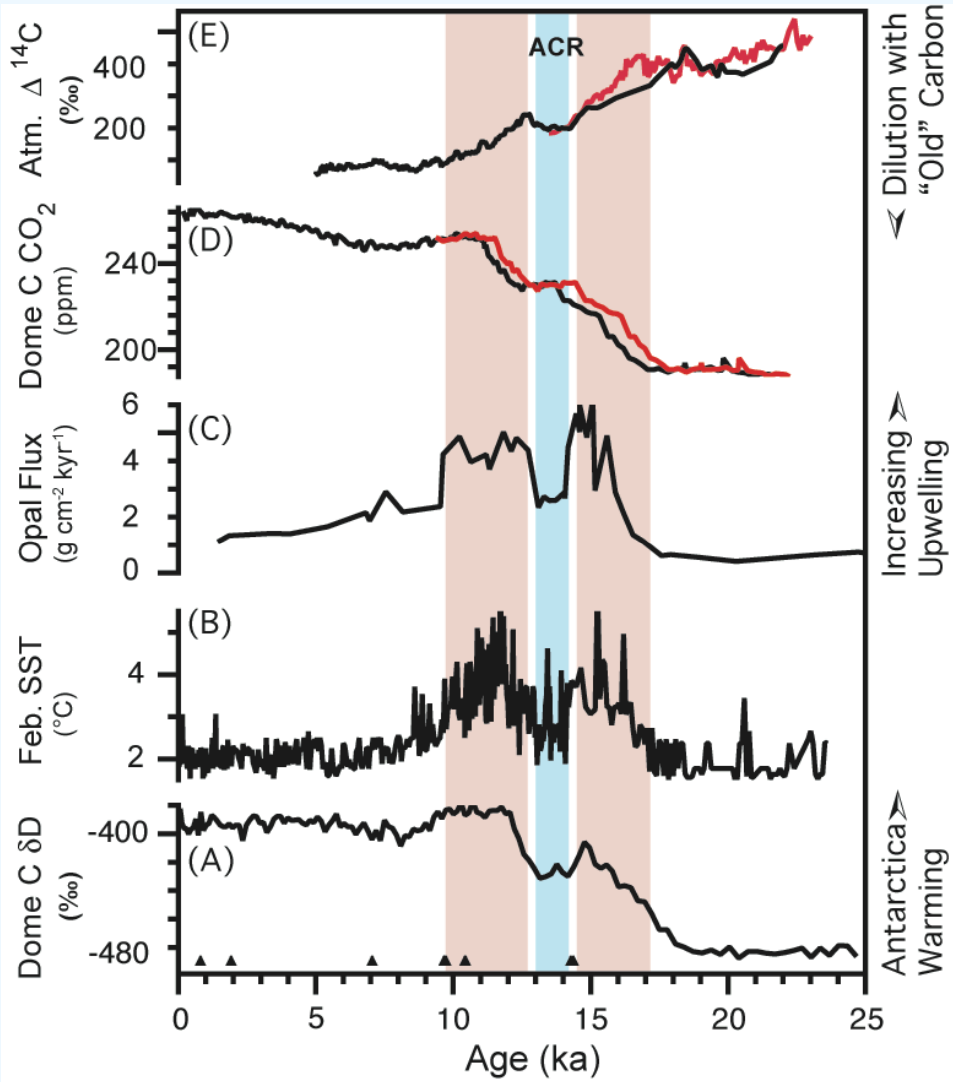
Ventilation and CO_2 exchange controlled by position of the SH Westerlies?



Northward shift of winds reduced ventilation during glacials.
Evidence for wind shift from precipitation proxy records.

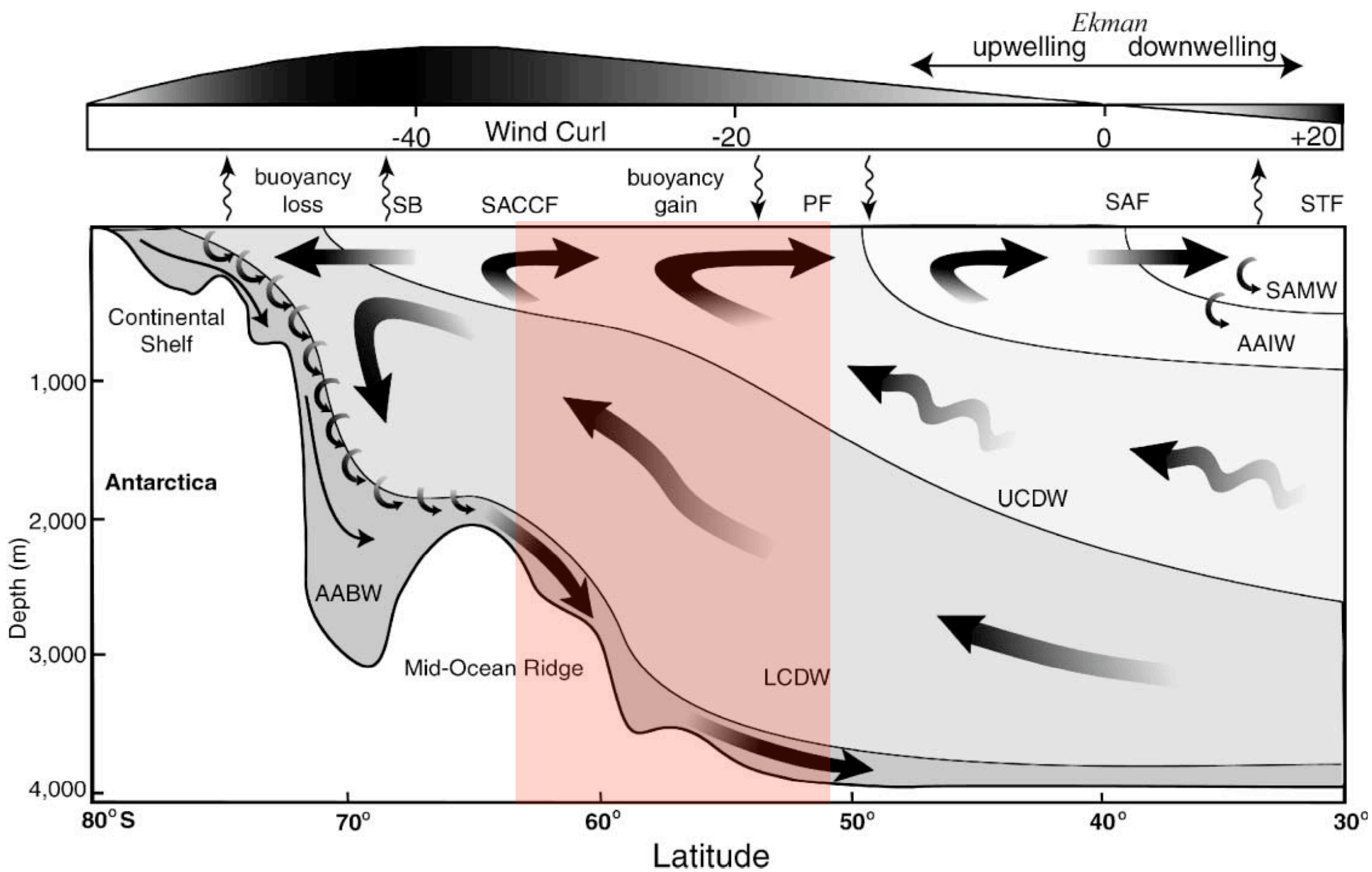
Toggweiler, 2006

Evidence for increased upwelling during deglaciations?



GOAL:
Demonstrate that opal flux in So. Ocean sediments is a proxy for upwelling, and that it is correlated with the deglacial rise in CO_2.

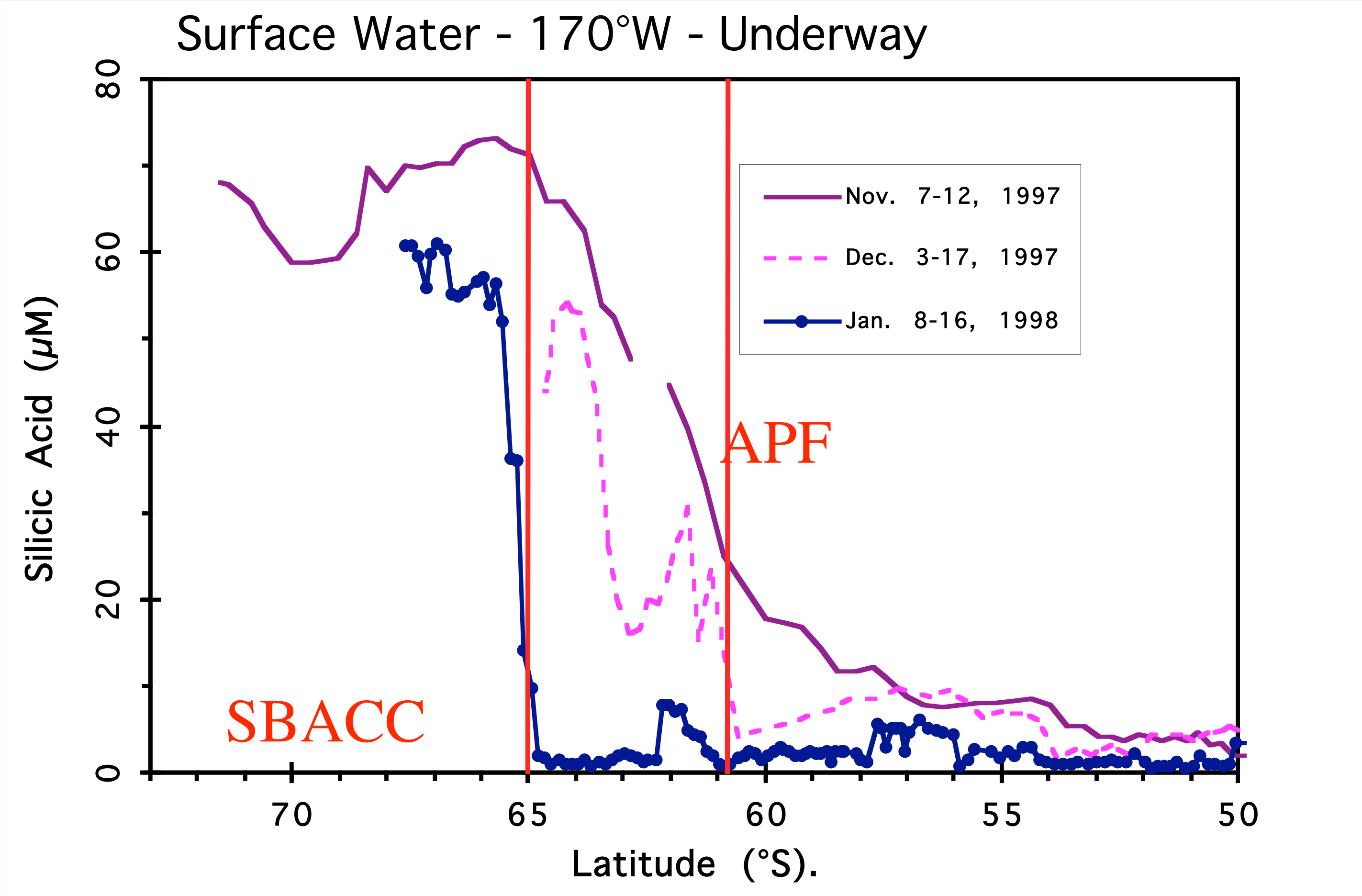
Principle: Upwelling brings nutrients (N, P, Si) to the surface as well as CO_2



Maximum nutrient supply is between the APF and the SACCF

Figure of K Speer redrawn by T Trull

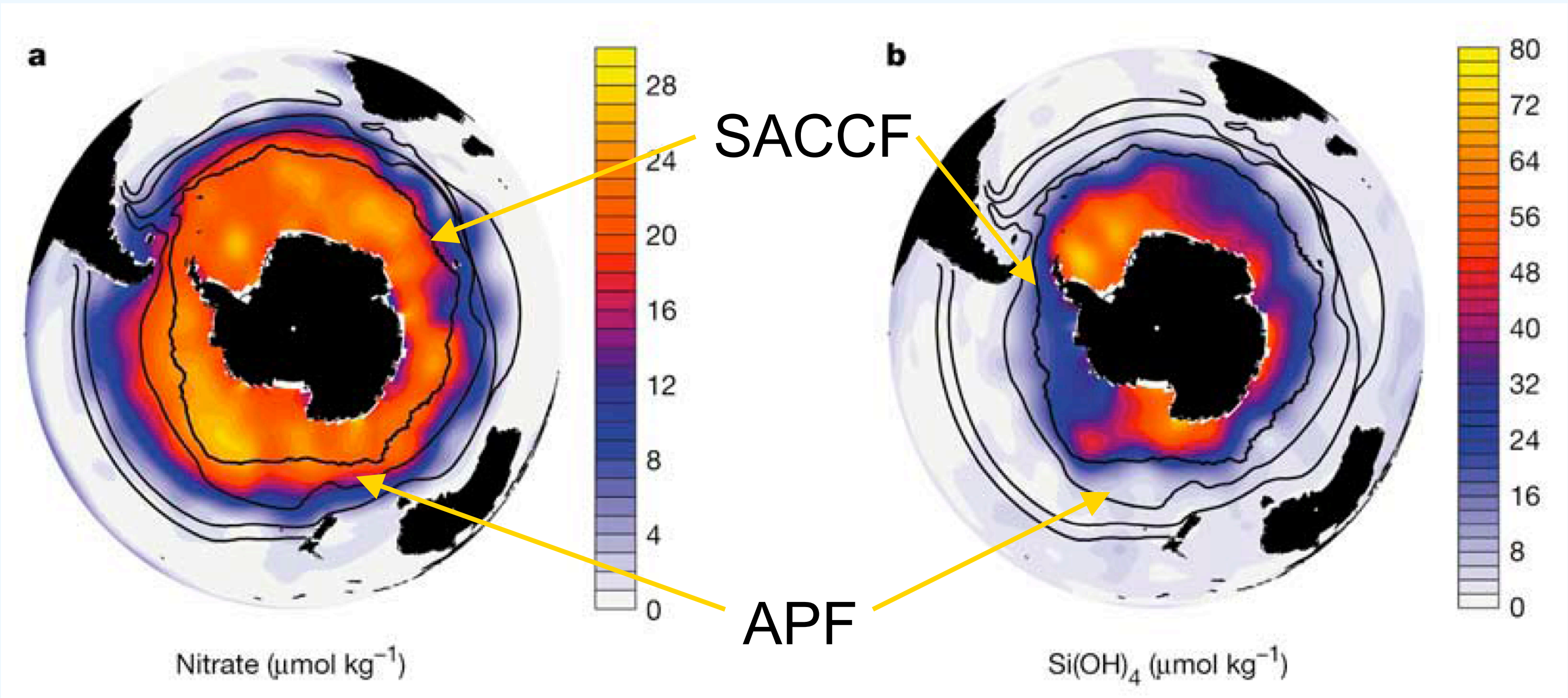
Principle: Between APF and SACCF Si is consumed by diatoms almost completely



Although N and P go largely unused, nearly all Si is consumed

Figure from US JGOFS/AESOPS

Principle: Between APF and SACCF Si is consumed by diatoms almost completely



Although N and P go largely unused, nearly all Si is consumed.
This is true throughout the Southern Ocean.

Figure from Sarmiento et al., 2004

Review: Features of the region between the APF and SACCF

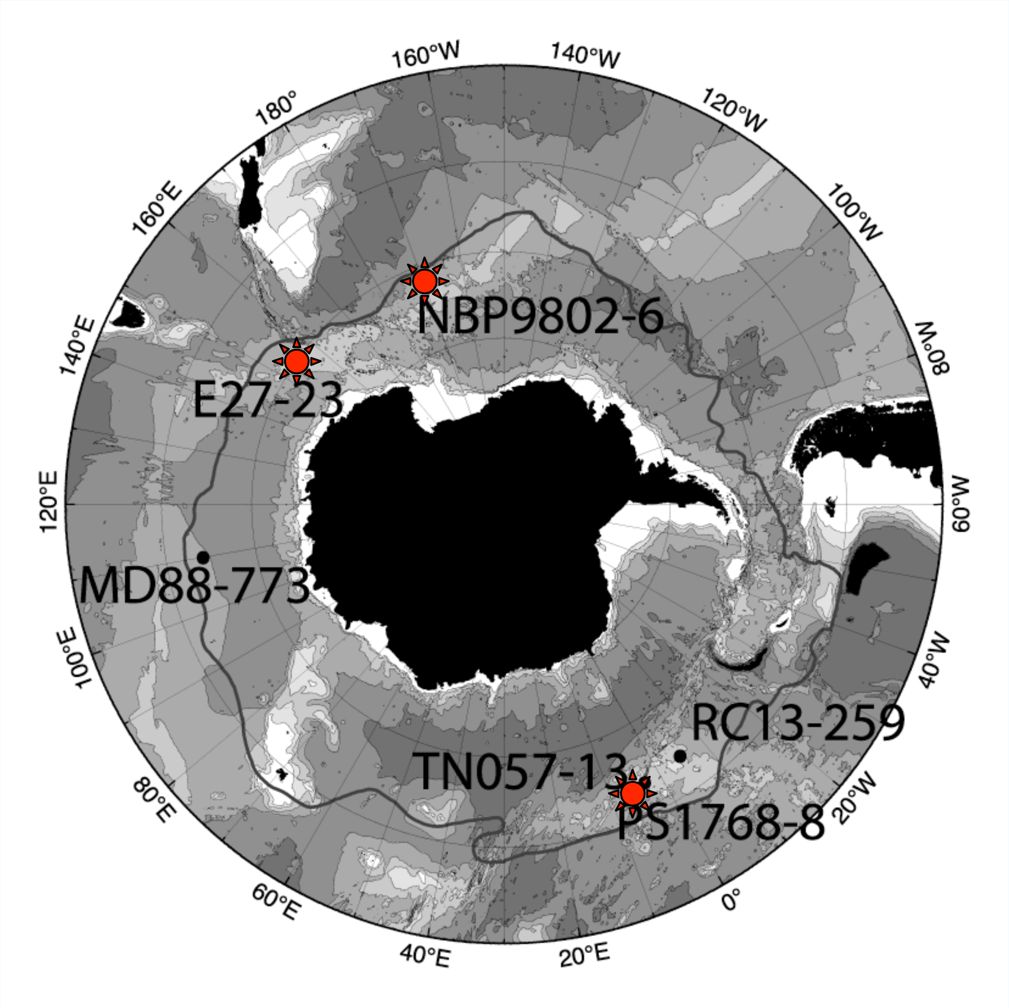
- Maximum upwelling and nutrient supply
- Nearly all Si used by diatoms
- Annual opal production is limited by Si
  i.e., by upwelling

Implication for the region between the APF and SACCF

Production of opal by diatoms in this region can exceed today's maximum values only by increasing the supply of dissolved Si…

…i.e. By increasing the rate of upwelling

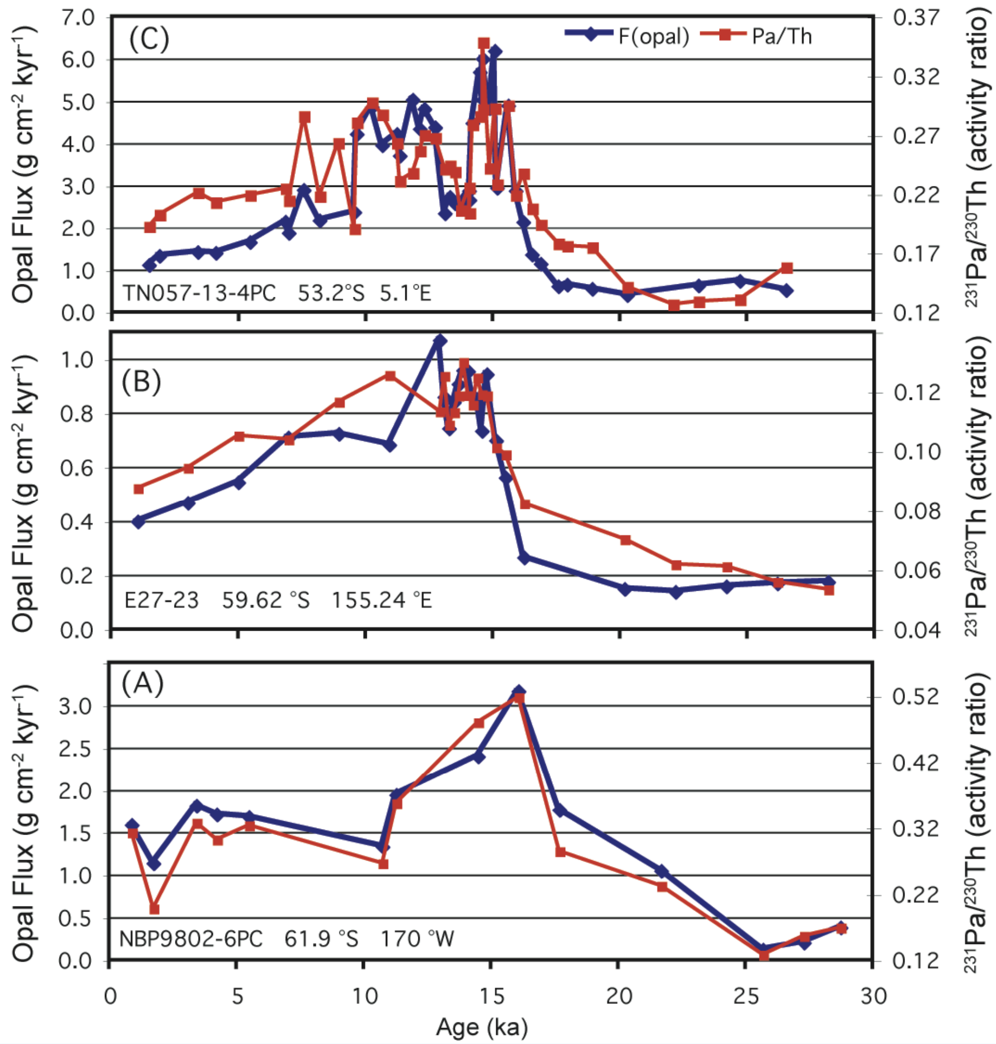
Sites where deglacial maxima in opal burial have been observed



Feature occurs:

- South of the APF
- In all sectors
- Results from selected sites

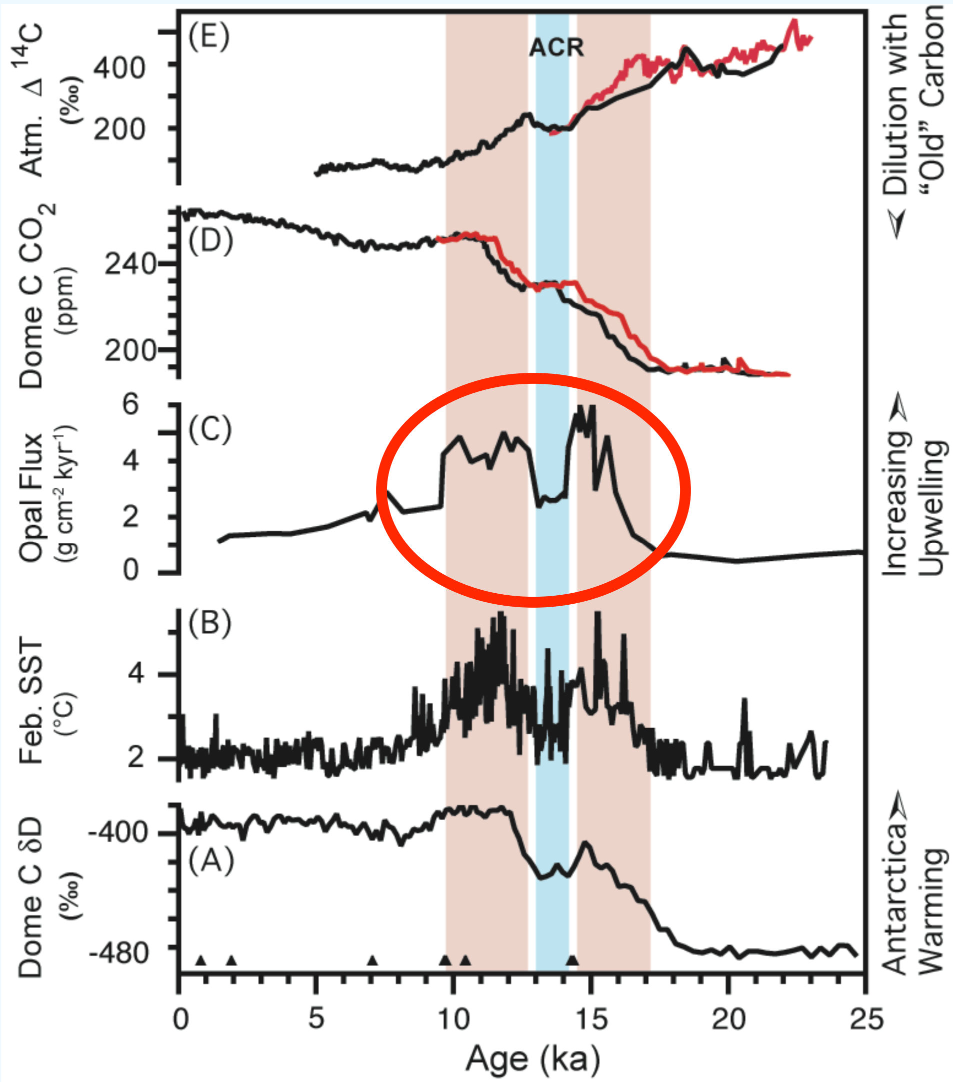
Deglacial maxima in opal burial in 3 sectors of the Southern Ocean



Opal burial flux:

- Peaks during deglaciation
- Correlates with $^{231}Pa/^{230}Th$
- Flux reflects diatom production, not opal preservation

Maximum So. Ocean upwelling coincided with deglacial rise in CO_2



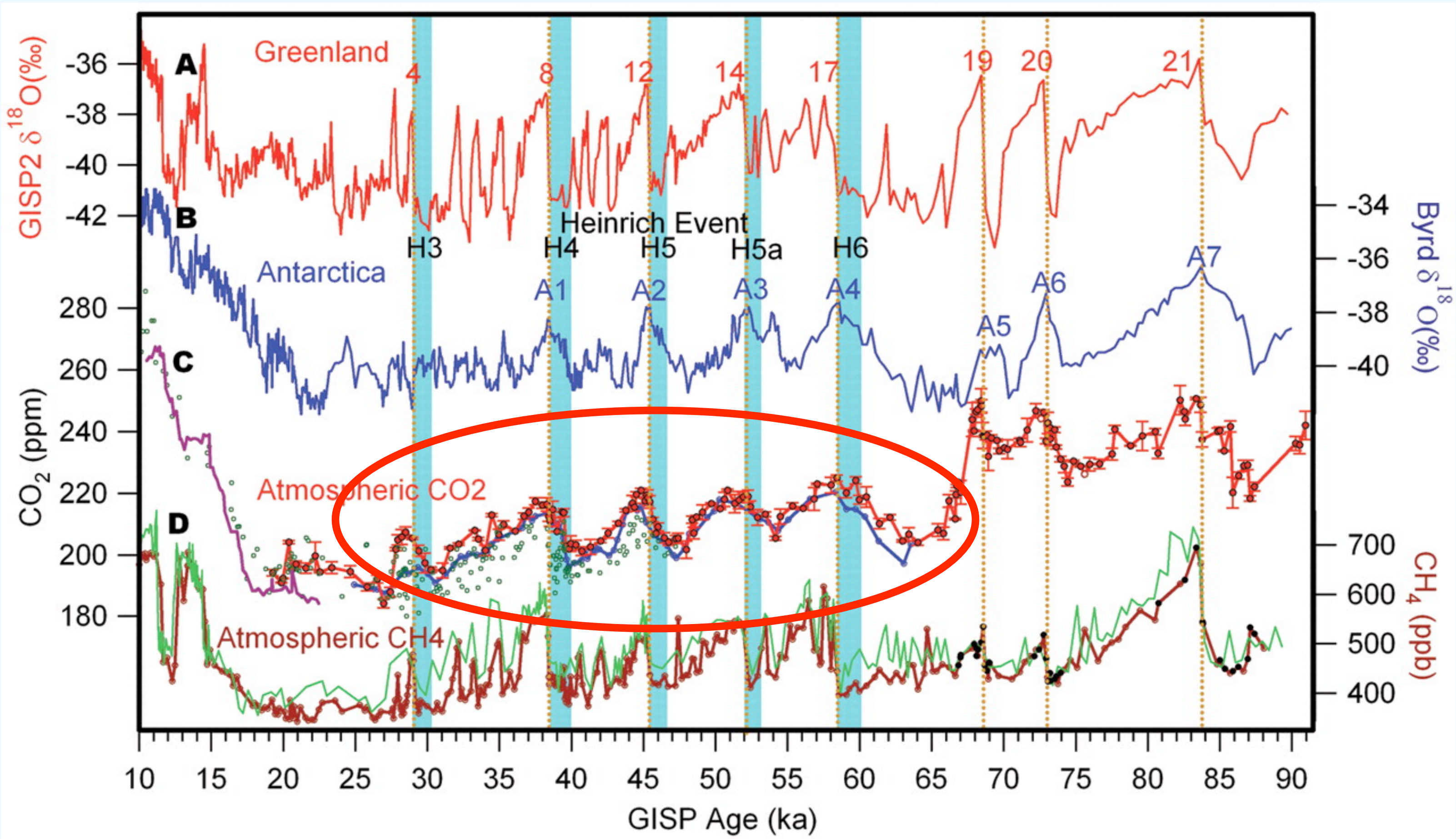
<u>SUMMARY OF EVIDENCE</u>:

Peak upwelling (opal flux) coincided with:

- warming in Antarctica,
- deglacial rise in CO_2
- deglacial drop in atm. $\Delta^{14}C$

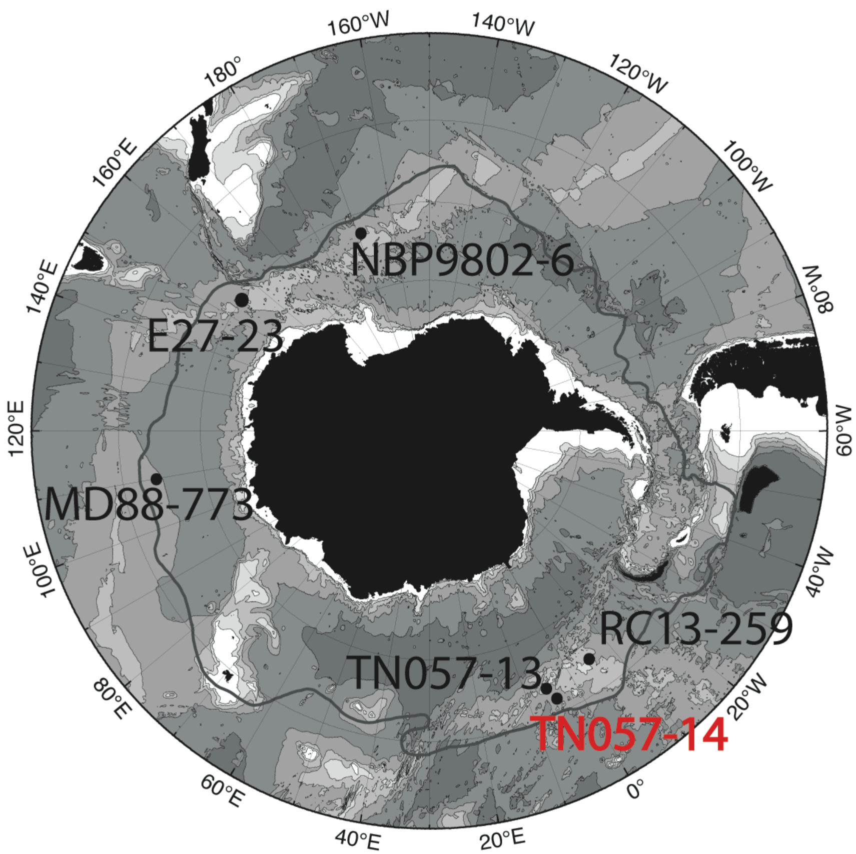
Including pause during ACR

Atm CO_2 increased during NH cold intervals surrounding earlier HEs



High resolution CO_2 record from Byrd ice core (red CO_2) extended through last glacial period (Ahn and Brook, 2008)

TN057-14: Opal flux upwelling proxy through last glacial period

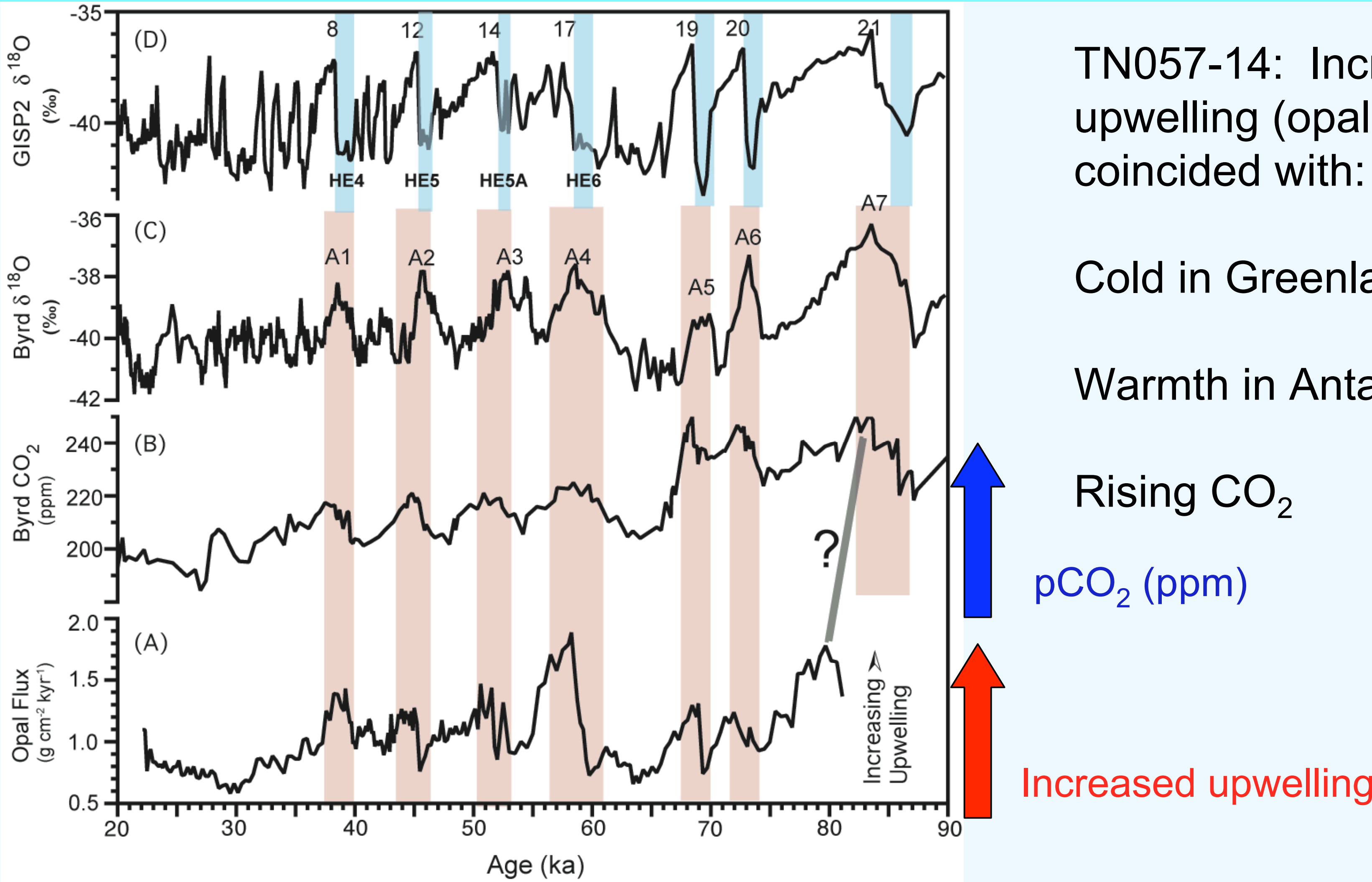


Sediment focusing changed with climate.

TN057-13 has an expanded deglacial section.

TN057-14 has an expanded section during the last glacial period.

Upwelling proxy correlates with pCO_2 throughout last glacial period



TN057-14: Increased upwelling (opal flux) coincided with:

Cold in Greenland

Warmth in Antarctica

Rising CO_2

Upwelling Summary

Deglacial Si supply to surface waters south of the APF exceeded supply before or after; increased upwelling is the only plausible cause. Upwelling correlated with rising atmospheric CO_2. Coincided with HS1 and the YD.

Increased upwelling (opal burial) coincided with earlier periods of rising atmospheric CO_2.

Wind-driven upwelling in the Southern Ocean is a primary mechanism driving changes in atmospheric CO_2.

Proposed Trigger

Heinrich Stadials (and Younger Dryas)

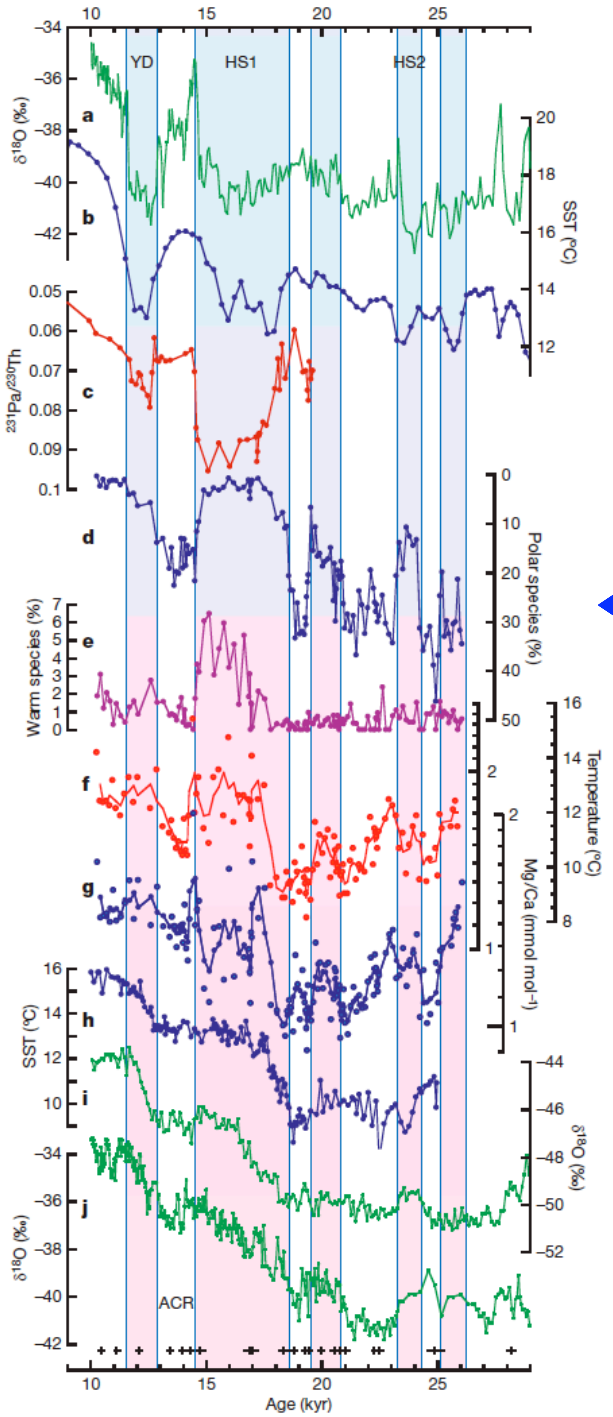
- Extreme cold in N. Hemisphere
- N. Hemisphere iceberg discharge
- Increased sea ice covered N. Atlantic
- **Reorganization of wind systems**

Teleconnection via winds
(global atmospheric circulation)

- **Change in N. Hemisphere Westerlies** during HE1 and YD recorded in Lake Lahontan level (Benson, 1995) and during YD recorded in German Lake sediments (Brauer et al., 2008)

- **Southward shift of ITCZ** and reorganization of monsoons during HEs (many references)

- **Southward shift of S. Hemisphere westerlies**:
  Shift in S Atlantic STF (Barker et al., 2009)
  Increased Precip in New Zealand (Whittaker, 2008)
  SST records off S. Chile (Lamy et al., 2007)
  Coupled GCMs (Timmermann et al., 2007)

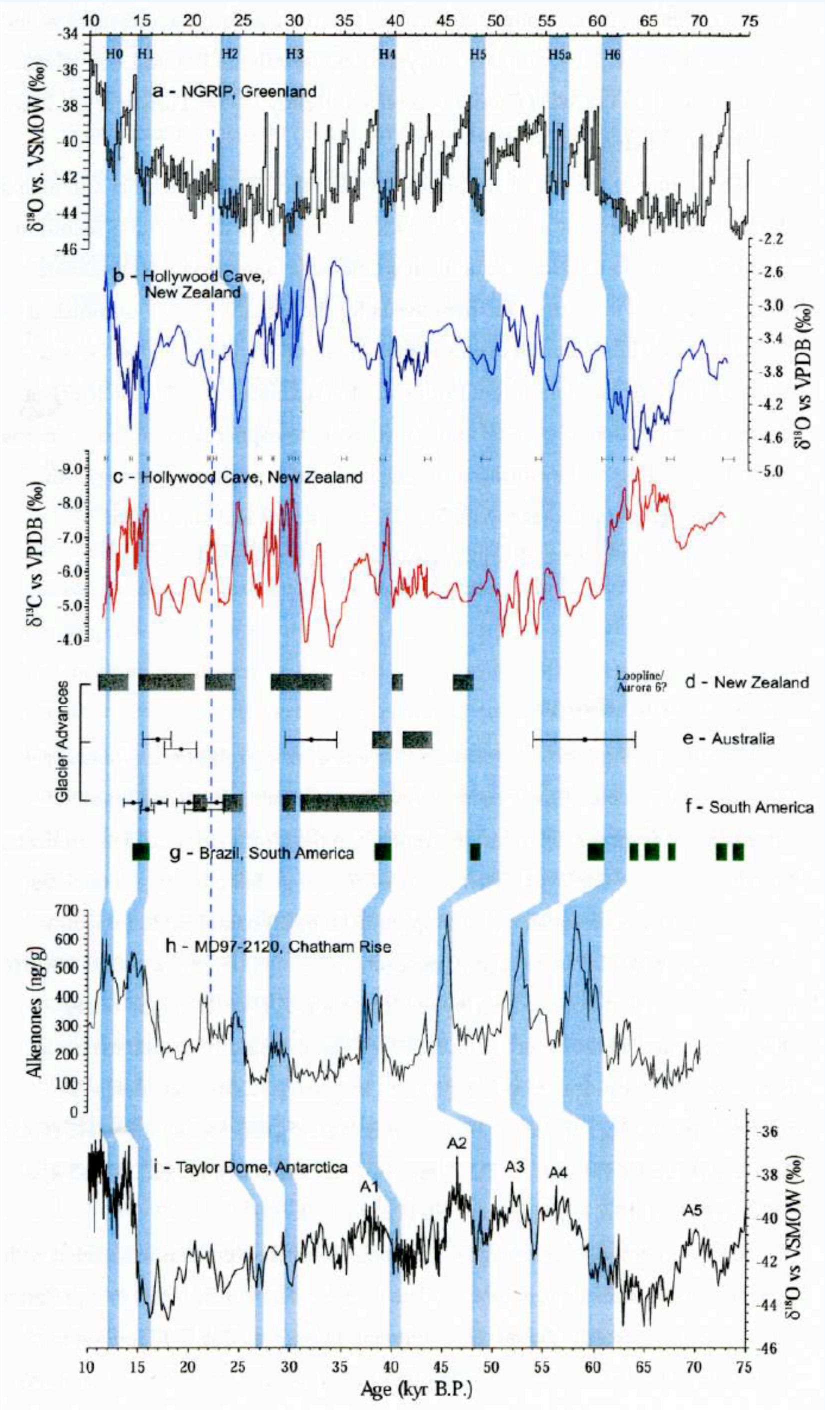


Rapid shift in S Atlantic STF

Rapid drops in polar foram species at 41°S (Atlantic) during HS1 and HS2 attributed to wind forcing and southward shift in the Subtropical Front.

(Barker et al., 2009)

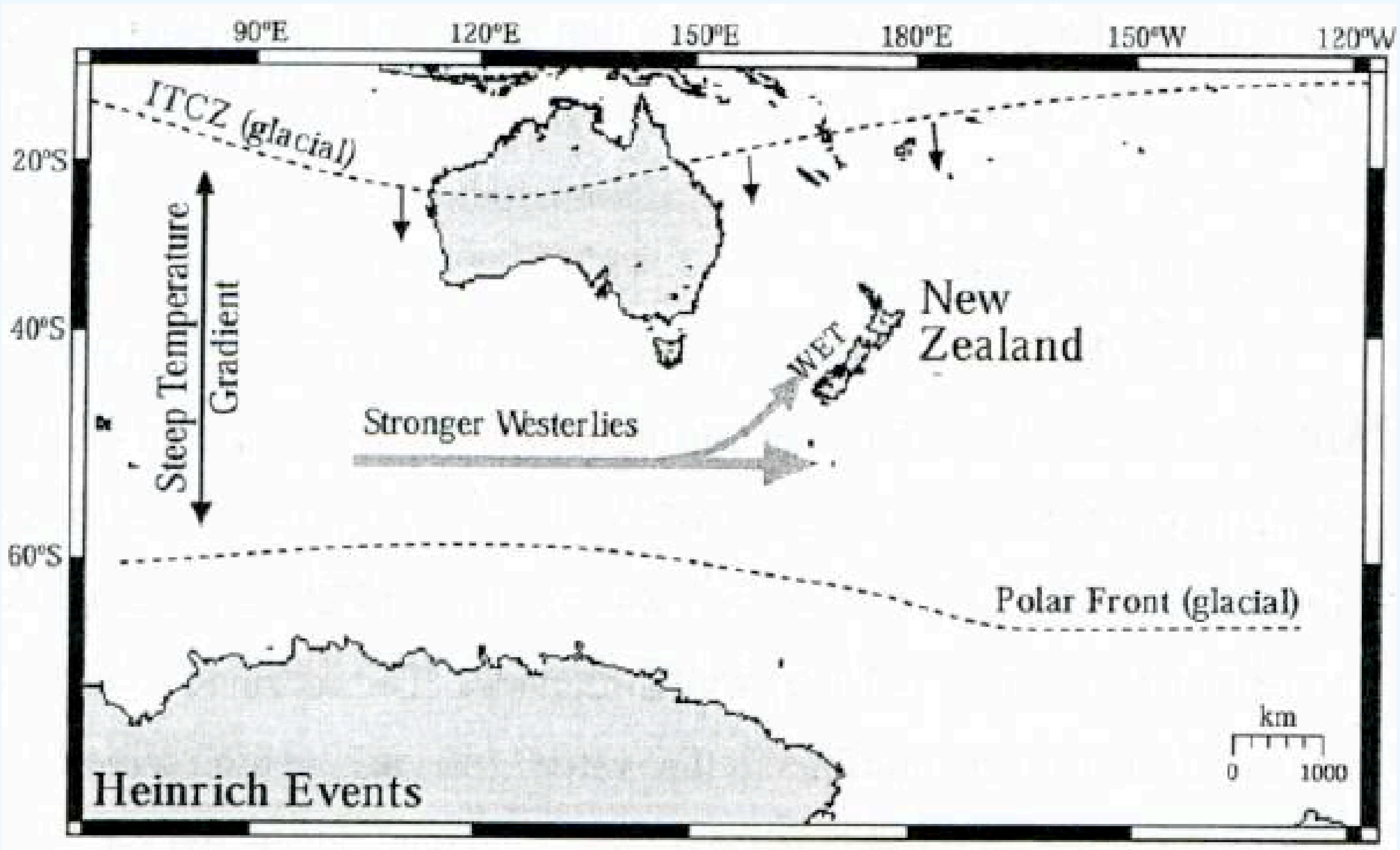
Increased precip over South Island of New Zealand during HEs



Reduction of $\delta^{18}O$ in speleothem $CaCO_3$ attributed to increased precipitation during Heinrich Events.

(Whittaker, 2008)

Increased precip over S. Island of New Zealand linked to <u>intensity</u> of westerlies



(Whittaker, 2008)

Wind stress at 60°S increases in response to waterhosing (~HEs)

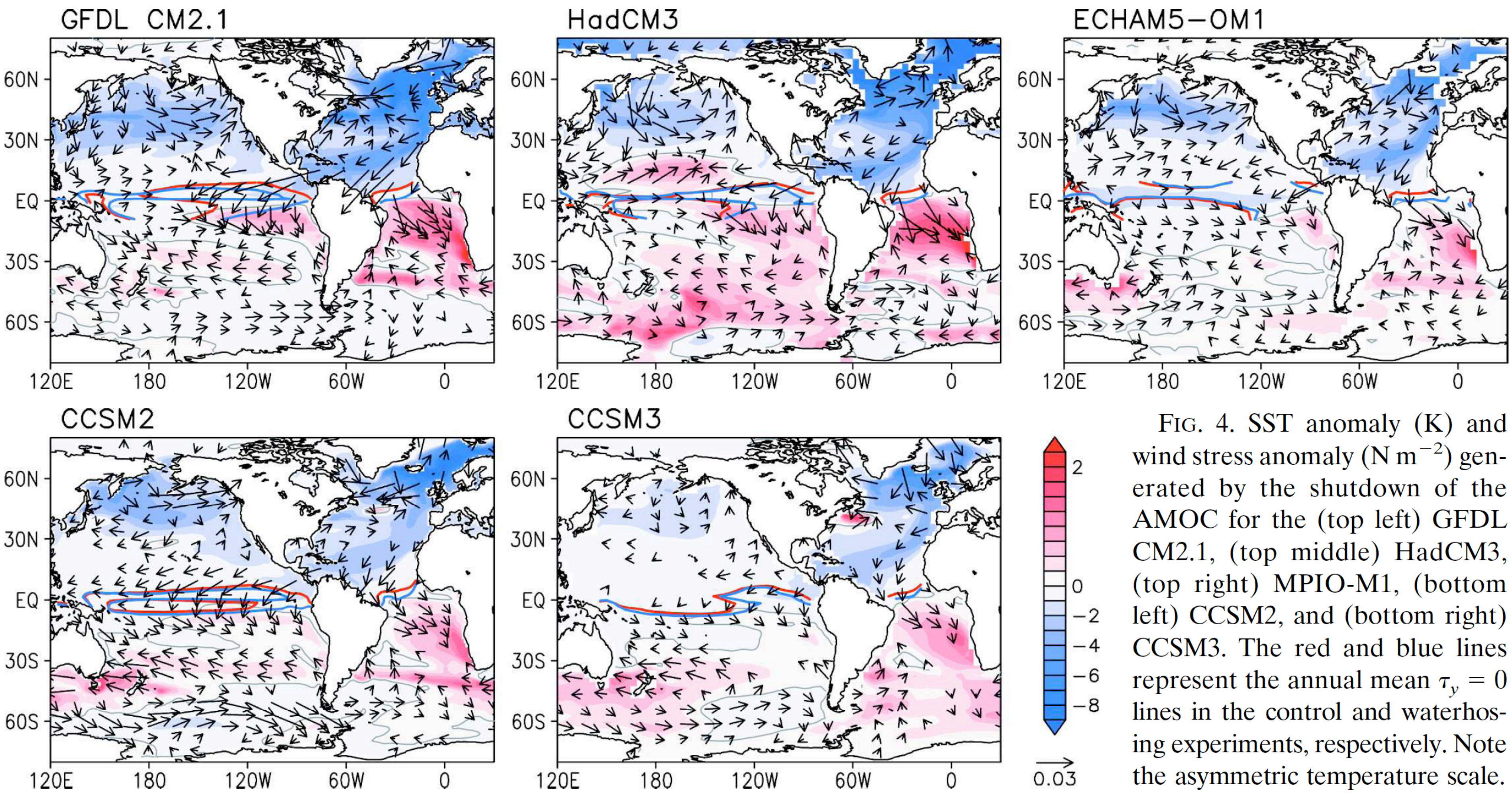
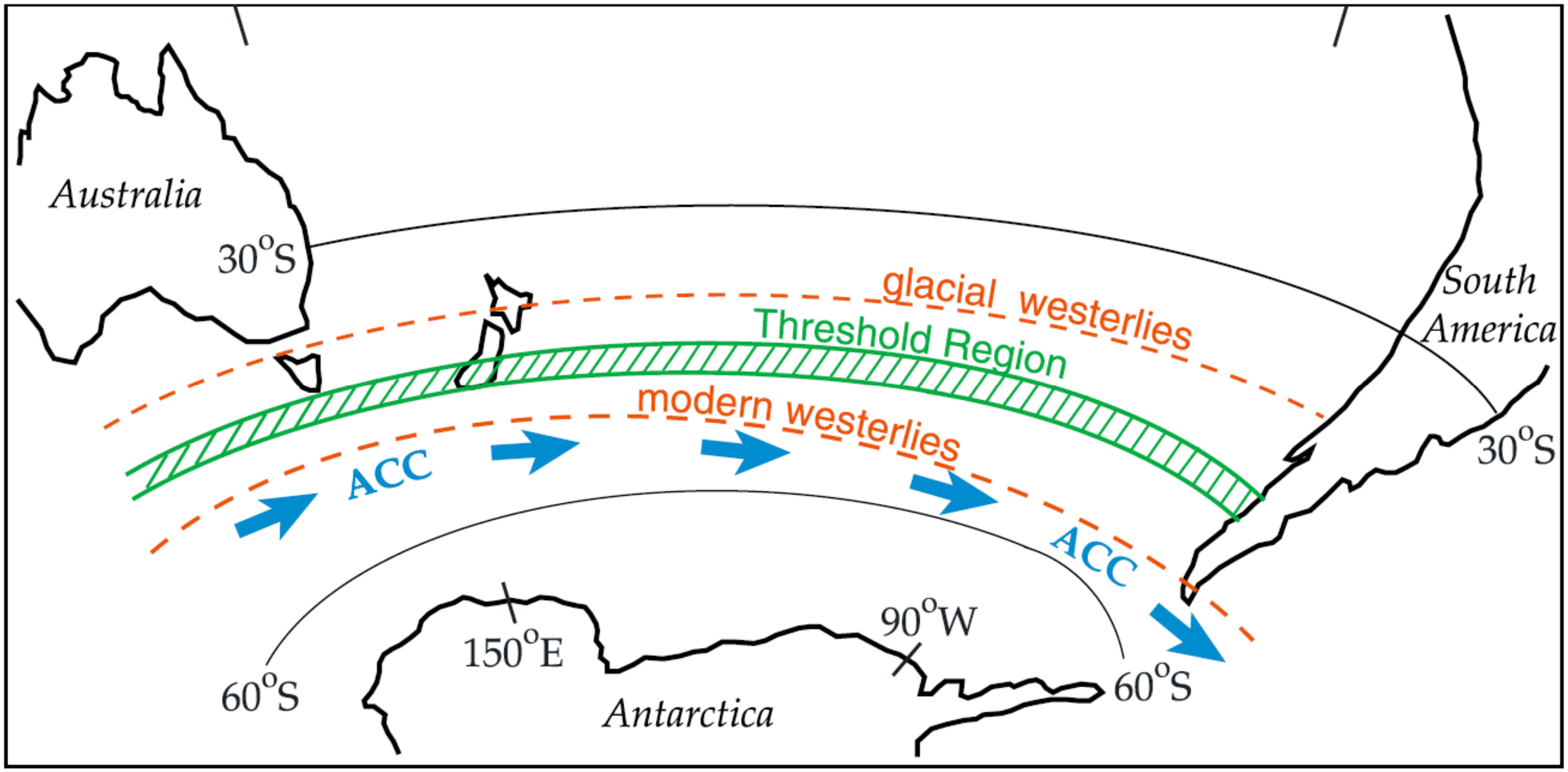


FIG. 4. SST anomaly (K) and wind stress anomaly (N m^{-2}) generated by the shutdown of the AMOC for the (top left) GFDL CM2.1, (top middle) HadCM3, (top right) MPIO-M1, (bottom left) CCSM2, and (bottom right) CCSM3. The red and blue lines represent the annual mean $\tau_y = 0$ lines in the control and waterhosing experiments, respectively. Note the asymmetric temperature scale.

Timmermann et al., 2007

Increased wind stress at 60°S drives upwelling in the So. Ocean



Maximum wind stress at the latitude of the Drake Passage favors upwelling of deep CO_2-rich water masses.

Toggweiler, 2006

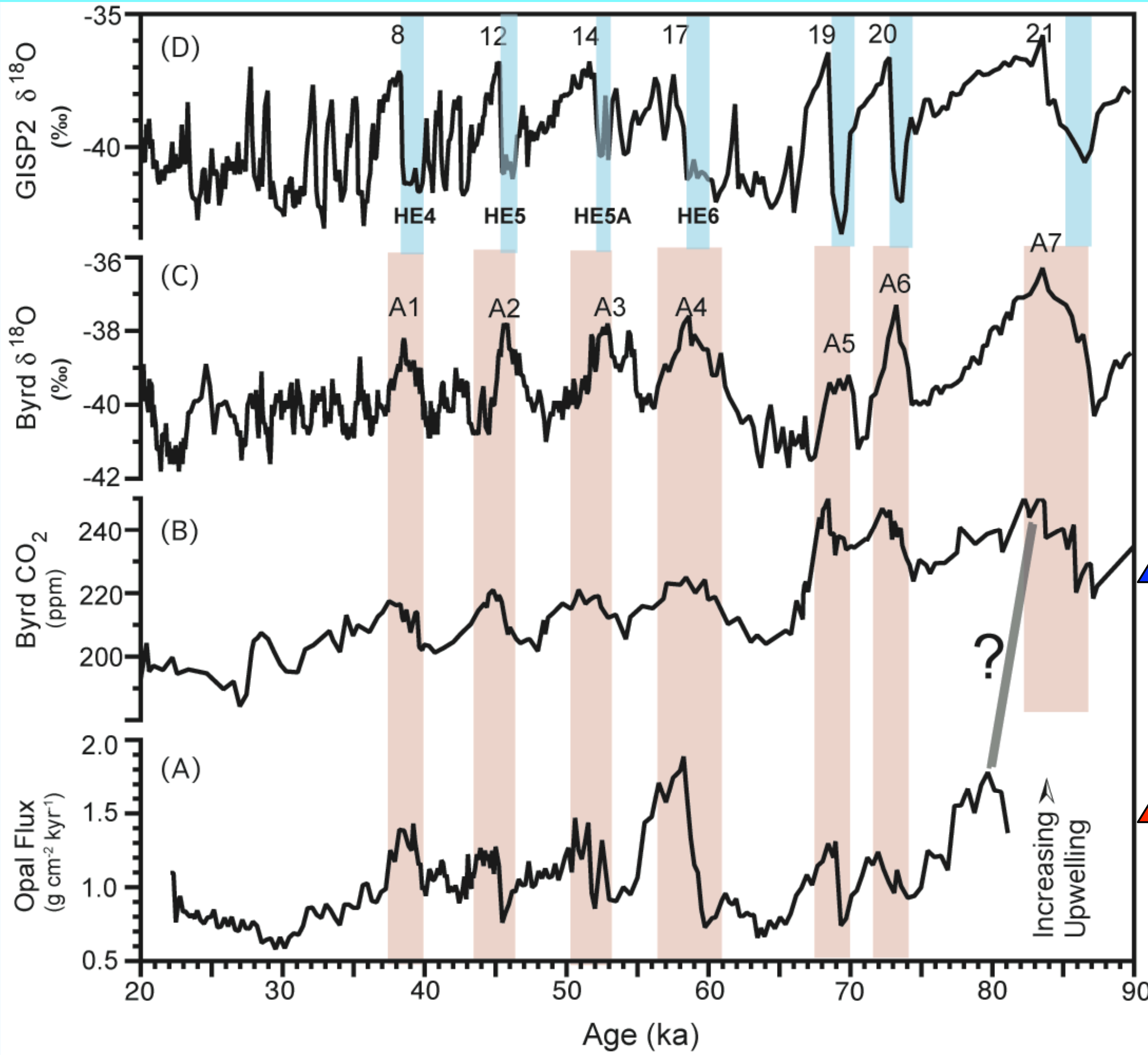
Abrupt Changes in Winds and CO_2

Extreme N Hemisphere cold events (HEs) induced reorganization of global atmospheric circulation.

Southward shift of SH Westerlies during HEs forced increased upwelling in the Southern Ocean and release of CO_2 from deep waters.

Asymmetry of polar temperature changes caused the southward shift of SH Westerlies to be more extreme during HEs than during the Holocene or warm interstadials.

Are these relationships limited to “glacial” conditions?



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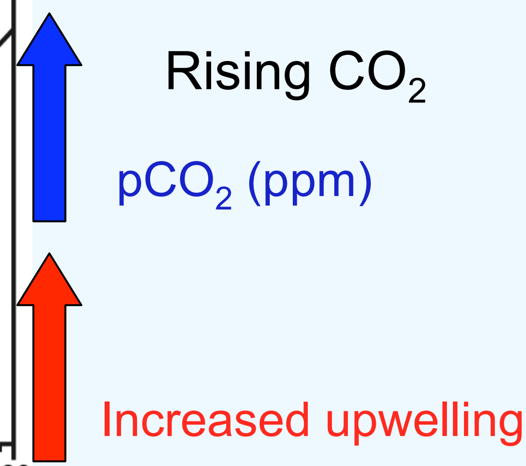
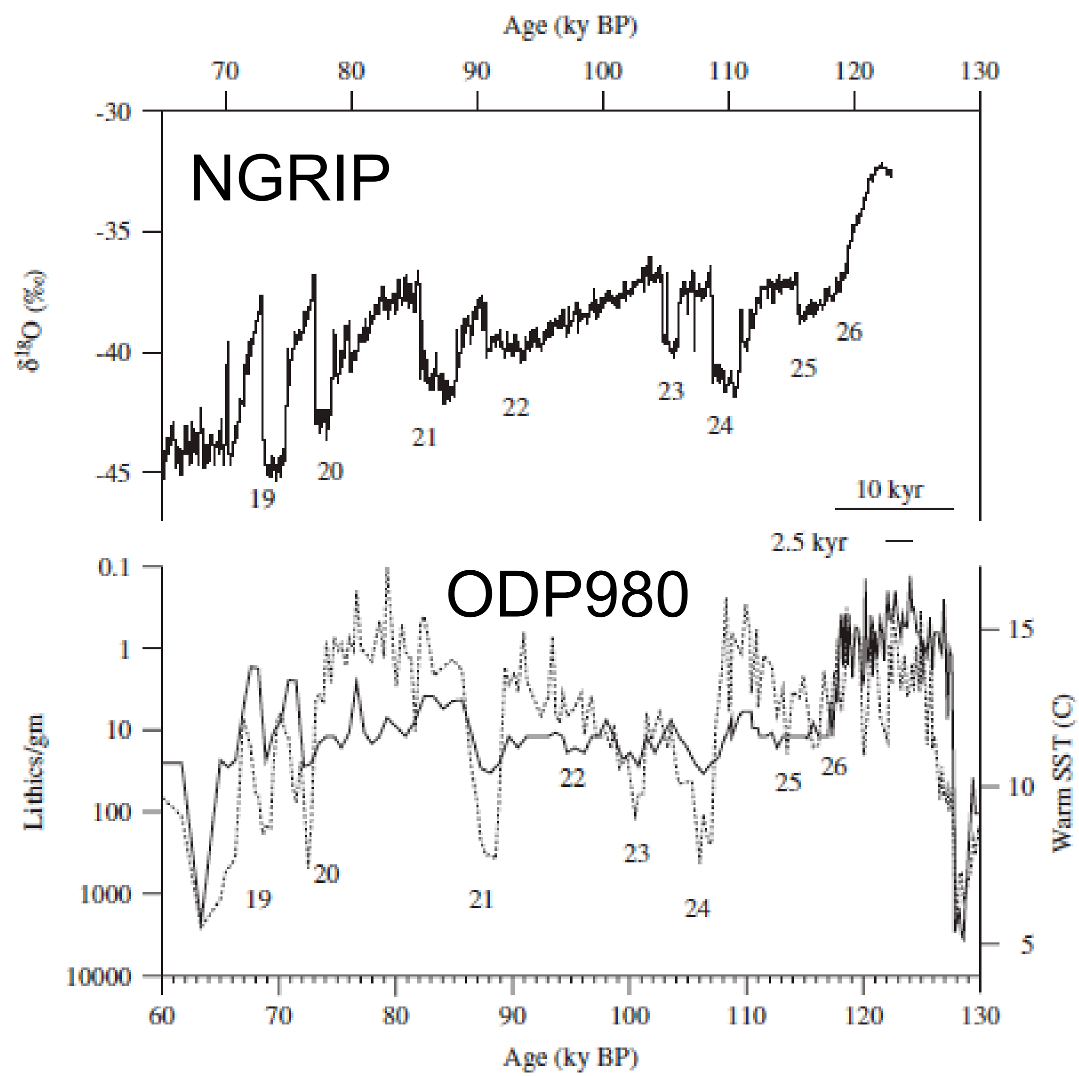
Rising CO_2



Earliest abrupt change of last climate cycle: Greenland Stadial 26 @ ~ 118 ka



GS 26:

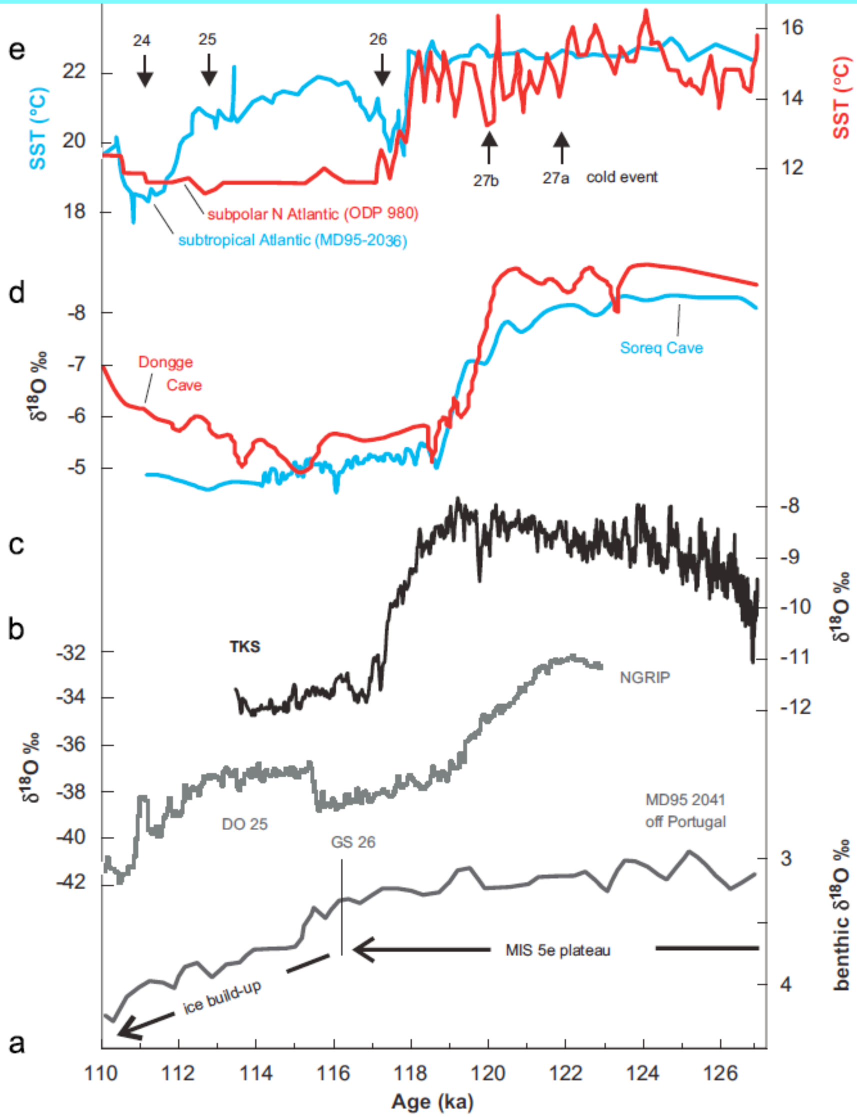
ODP 980 (N Atlantic) record shows cooling SST and detectable increase in IRD.

Oppo et al., 2006

Note different age models.

SST = solid
IRD = dashed

Earliest abrupt change of last climate cycle: GS 26 has widespread footprint



Atlantic SST:
Subpolar
Subtropical

Speleothems:
China
Israel

Austrian alps speleothem

NGRIP

Although age models differ slightly, many records show abrupt changes at ~118ka consistent with cooling in the N Atlantic.

Meyer et al., 2008

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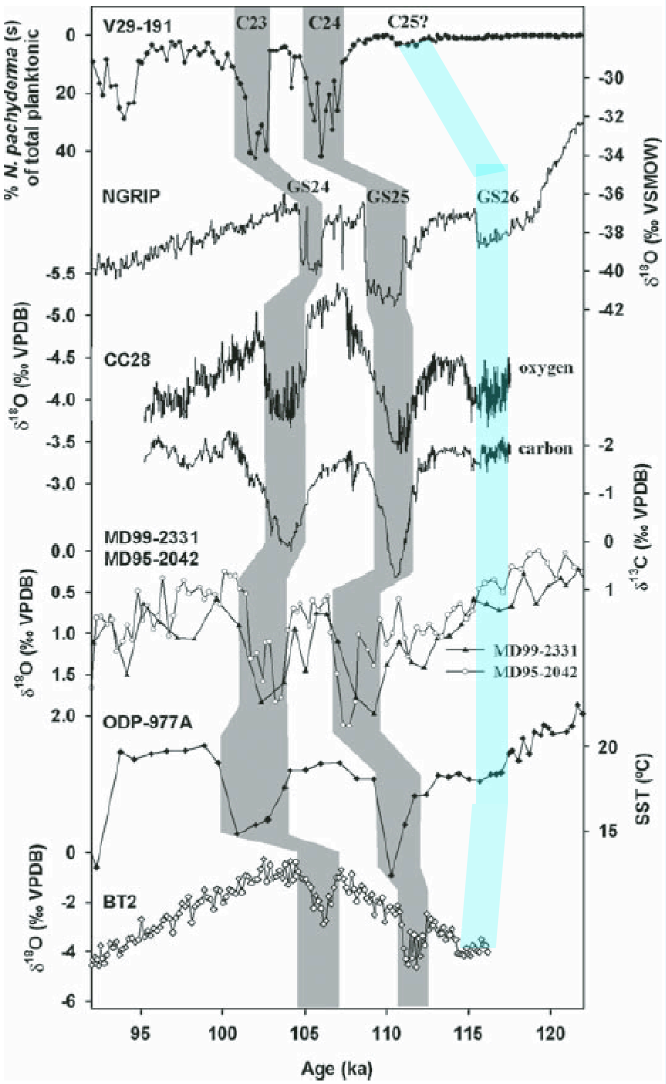


N Atlantic Polar foraminifera

GS26 = C25

NGRIP

Italian Speleothems

Italian Speleothems

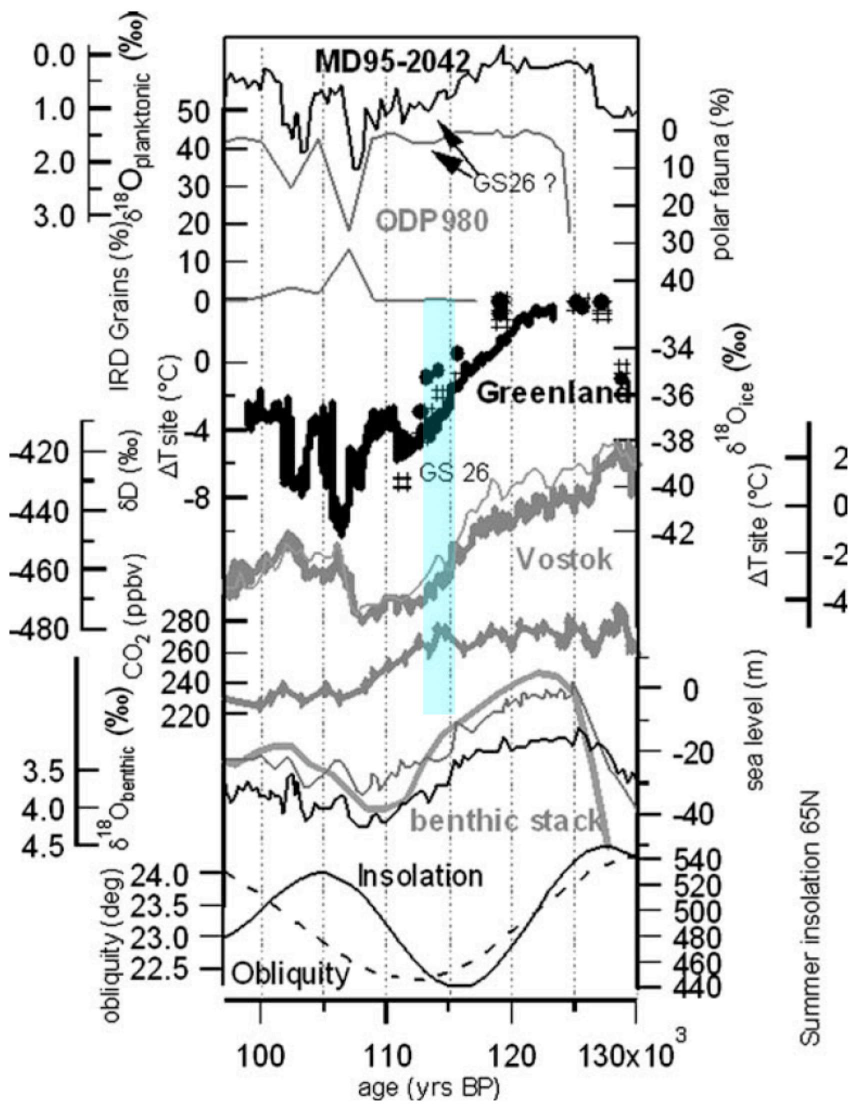
Iberian margin Planktic forams

W Med. Planktic forams

Brazilian speleothem

Drysdale et al., 2007

Earliest abrupt change of last climate cycle: GS 26 has features of Heinrich Stadials



NGRIP

Vostok ΔT site
Local temp.

Atm. CO_2

NGRIP and Vostok aligned by gases:

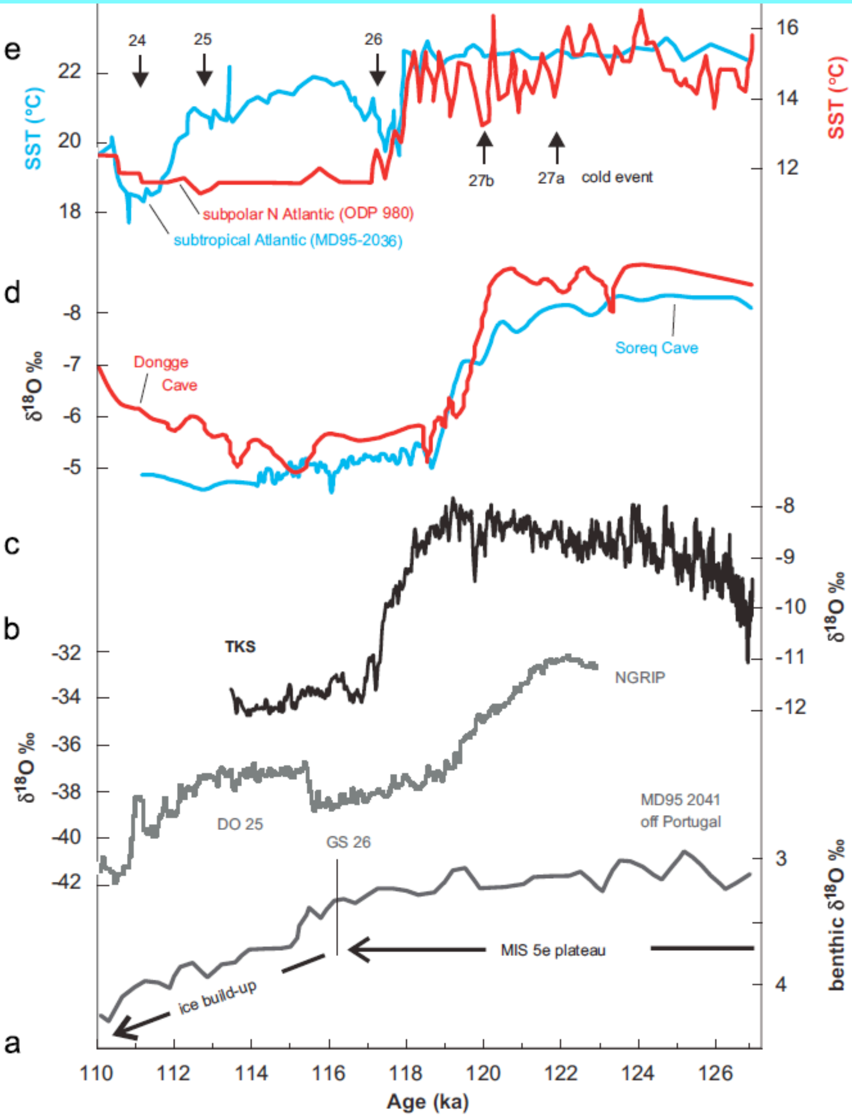
Cooling in Greenland

Warming in Antarctica

Rising CO_2

Landais et al., 2006

Earliest abrupt change of last climate cycle: GS 26 has widespread footprint



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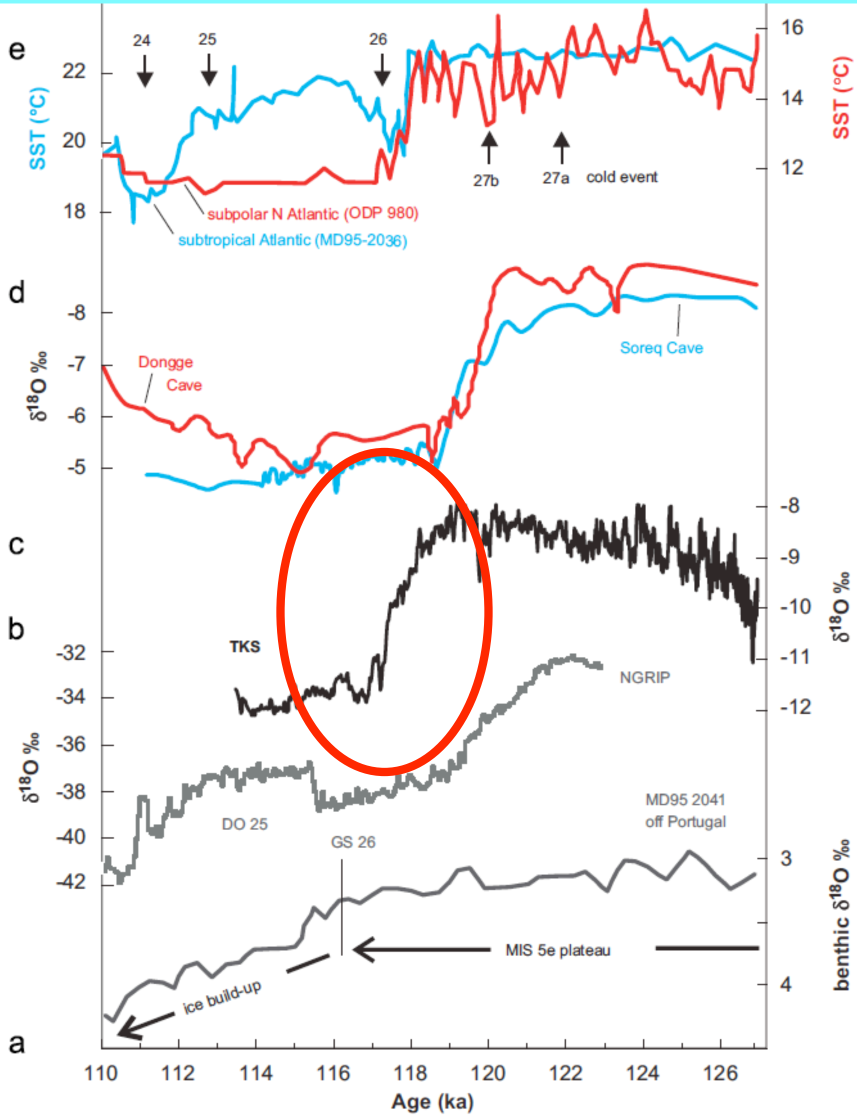

Austrian alps speleothem

Austrian Alps speleothem:

Abrupt drop in δ^{18}O at 118ka attributed to increased seasonality.

Colder winters.

Consistent N Atlantic sea ice effect of Denton et al., 2005.

Meyer et al., 2008

Conclusions: Abrupt NH Coolings…

Triggered by (freshwater-induced) expansion of
N Atlantic sea ice.

Transmitted globally by winds.

Raise atm CO_2 by upwelling in So. Ocean.

Terminations are a special case.

Sequence may have occurred as early as 118 ka.
Terminating last interglacial.
With small NH ice sheets.

Recommendations: Future work…

Test systematic pattern of N Atlantic sea ice trigger and global wind teleconnection during Abrupt Change events.

Discriminate between consequences of winds versus AMOC.

Investigate other factors affecting global winds and their impact on CO_2 and climate.