The HadOCC and Diat-HadOCC models

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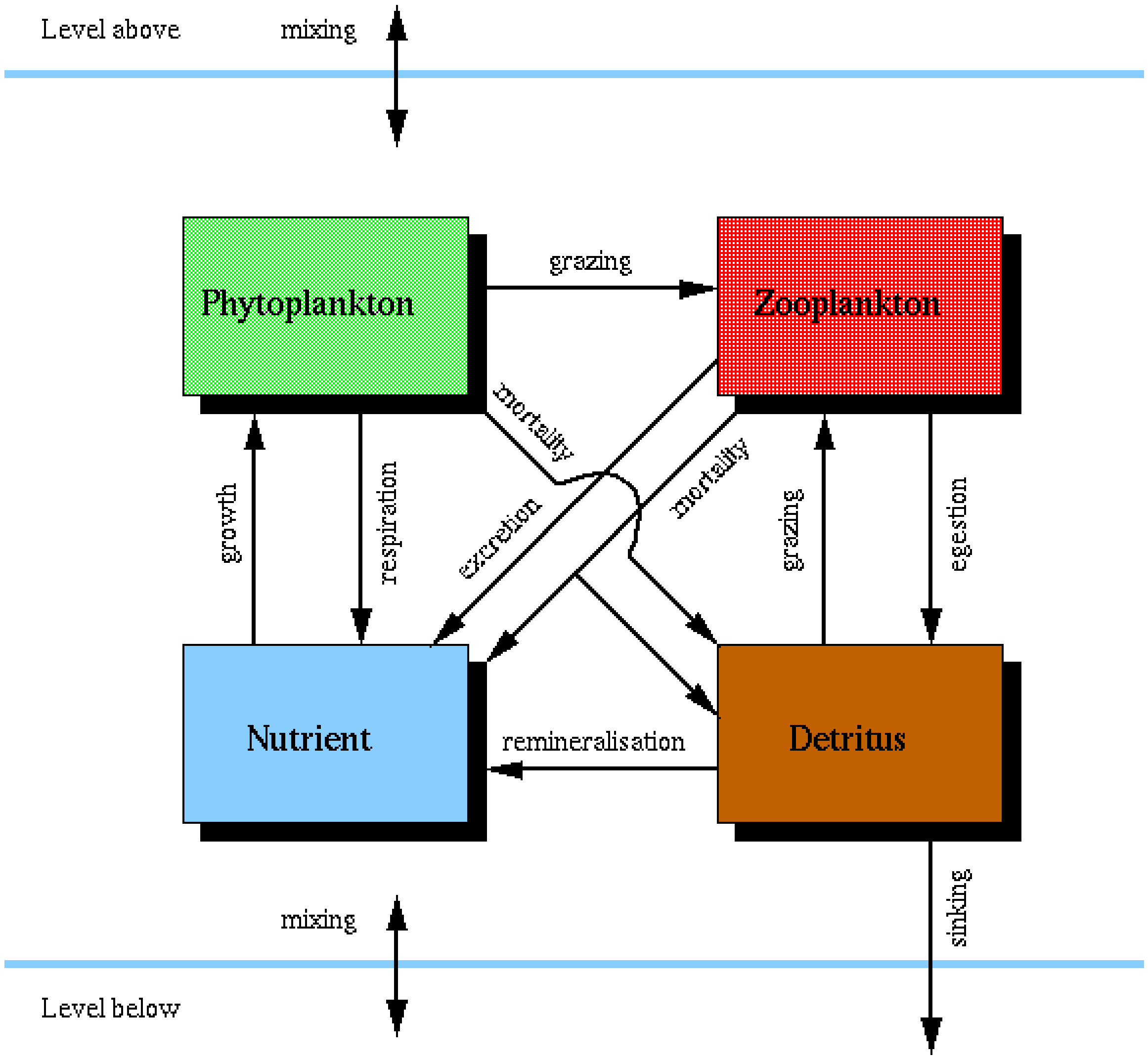
The Hadley Centre Ocean Carbon Cycle (HadOCC) model

- Originally developed during the 1990s for HadCM3
- Described in Palmer & Totterdell (2001)
- Designed to investigate the open-ocean carbon cycle and the biological pump
- Simple structure, heavily parameterised
- Used in the Cox et al. (2000) study and in C4MIP
- Used in the MO’s ocean forecast model

HadOCC: structure



The Diat-HadOCC model

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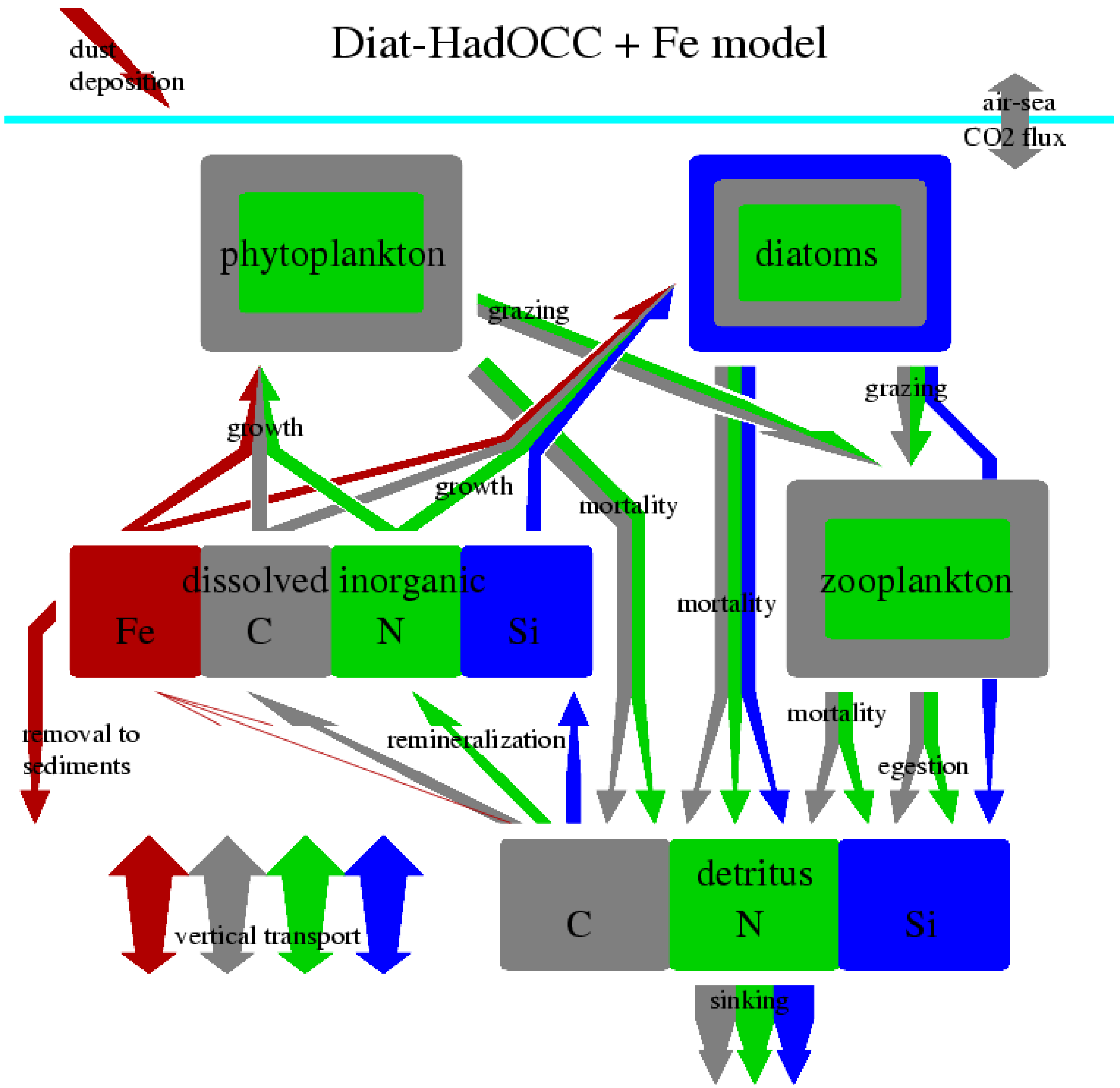
- A development of the HadOCC model, undertaken in collaboration with Mike Fasham in early 2000s
- Full description in prep (but equations available)
- Splits phytoplankton into diatoms and non-diatoms, splits detritus into separate elemental parts, adds silicate and iron cycles, adds parameterisation for DMS
- Simple structure, heavily parameterised
- Used as the ocean BGC component of HadGEM2-ES for CMIP5/AR5 simulations

Diat-HadOCC: structure



Primary production

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$$dm_{PP} = Dm \cdot \frac{DIN}{k_{DIN}^{Dm} + DIN} \cdot \frac{Si}{k_{Si}^{Dm} + Si} \cdot PP(z, sol_{noon}, dlh, chl_{ttl}, P_m^{Dm}, \alpha^{Dm})$$

$$ph_{PP} = Ph \cdot \frac{DIN}{k_{DIN}^{Ph} + DIN} \cdot PP(z, sol_{noon}, dlh, chl_{ttl}, P_m^{Ph}, \alpha^{Ph})$$

- Realisable growth calculated according to Anderson (1993): parameterises changing spectral distribution.
- Achieved growth amended using multiplicative nutrient limitations
- Effect of iron is to alter maximum growth rate
- No temperature effect

Effects of iron in Diat-HadOCC

$$\Pi = \Pi_{replete} + (\Pi_{deplete} - \Pi_{replete}) \cdot \frac{1}{1 + \frac{FeT}{k_{FeT}}}$$

$$\begin{aligned}
FeT &= FeL + FeF \\
LgT &= FeL + LgF \\
K_{FeL} &= \frac{FeL}{FeF \cdot LgF} \\
B &= K_{FeL} \cdot (LgT - FeT) - 1 \\
FeF &= FeT - LgT \\
&\quad + \frac{1}{2 \cdot K_{FeL}} \cdot \left(B + \sqrt{B^2 - 4 \cdot K_{FeL} \cdot LgT} \right) \\
fe_{adsorp} &= \Pi_{ads}^{FeF} \cdot FeF
\end{aligned}$$

- (Total) dissolved iron (free and complexed) alters the value of five parameters: diatom max growth rate, nd-phytoplankton max growth rate, diatom Si:N ratio, zooplankton base feeding preference for diatoms and zooplankton mortality rate (in CMIP5 runs only the first varied)
- Iron is taken up by diatoms and nd-phyto in a fixed ratio to carbon, and passed through Dm, Ph and Zp in that ratio
- There is no iron in detritus
- The final sink for iron is adsorption of free iron onto (implicit) mineral particles

Grazing: HadOCC

$$
\begin{aligned}
food &= R_{b2n}^{Ph} \cdot Ph \; + \; R_{b2n}^{Dt} \cdot Dt \\
grz_{ttl} &= \frac{g_{max} \cdot R_{b2n}^{Zp} \cdot Zp \cdot (\, food \; - \; food_{min}\,)^2}{(g_{sat})^2 \; + \; (\, food \; - \; food_{min}\,)^2} \\
ph_{grz} &= grz_{ttl} \cdot \frac{Ph}{food} \\
dt_{grz} &= grz_{ttl} \cdot \frac{Dt}{food}
\end{aligned}
$$

- Generic grazer eats phytoplankton and detritus
- No preference or “switching”
- Phyto/detritus ingested in proportion to its abundance (in biomass units, allowing for different C:N)
- Holling Type 3 functional form
- 77% of grazed material enters gut; remainder is “messy feeding”, 90% of which becomes detritus, 10% DIN or DIC

Grazing: Diat-HadOCC

$$food = dprf_{Dm} \cdot R_{b2n}^{Dm} \cdot Dm + dprf_{Ph} \cdot R_{b2n}^{Ph} \cdot Ph + dprf_{Dt} \cdot (R_{b2n}^{DtN} \cdot DtN + R_{b2c}^{DtC} \cdot DtC)$$

$$dm_{grz} = \frac{dprf_{Dm} \cdot Dm \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} + food}$$

$$dmsi_{grz} = \frac{dprf_{Dm} \cdot DmSi \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} + food}$$

$$ph_{grz} = \frac{dprf_{Ph} \cdot Ph \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} + food}$$

$$dtn_{grz} = \frac{dprf_{Dt} \cdot DtN \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} + food}$$

$$dtc_{grz} = \frac{dprf_{Dt} \cdot DtC \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} + food}$$

- Generic grazer eats diatoms, nd-phytoplankton and detritus
- Fasham-style “switching” grazer: dynamic preferences based on (non-equal) base prefs and abundances
- Holling Type 2 functional form
- 77% of grazed material enters gut; remainder is “messy feeding”, 90% of which becomes detritus, 10% DIN or DIC

Secondary production

$$assim_N = f_{ingst} \cdot (\beta^{Dm} \cdot dm_{grz} + \beta^{Ph} \cdot ph_{grz} + \beta^{Dt} \cdot dtn_{grz})$$

$$assim_C = f_{ingst} \cdot (\beta^{Dm} \cdot R^{Dm}_{c2n} \cdot dm_{grz} + \beta^{Ph} \cdot R^{Ph}_{c2n} \cdot ph_{grz} + \beta^{Dt} \cdot dtn_{grz})$$

$$grz_{Zp} = MIN\left(assim_N, \frac{assim_C}{R^{Zp}_{c2n}}\right)$$

$$grz_{DtN} = (1 - f_{ingst}) \cdot (1 - f_{messy}) \cdot (dm_{grz} + ph_{grz} + dtn_{grz}) + f_{ingst} \cdot ((1 - \beta^{Dm}) \cdot dm_{grz} + (1 - \beta^{Ph}) \cdot ph_{grz} + (1 - \beta^{Dt}) \cdot dtn_{grz})$$

$$grz_{DtC} = (1 - f_{ingst}) \cdot (1 - f_{messy}) \cdot (R^{Dm}_{c2n} \cdot dm_{grz} + R^{Ph}_{c2n} \cdot ph_{grz} + dtc_{grz}) + f_{ingst} \cdot ((1 - \beta^{Dm}) \cdot R^{Dm}_{c2n} \cdot dm_{grz} + (1 - \beta^{Ph}) \cdot R^{Ph}_{c2n} \cdot ph_{grz} + (1 - \beta^{Dt}) \cdot dtc_{grz})$$

$$grz_{dtsi} = dmsi_{grz}$$

$$grz_{DIN} = (1 - f_{ingst}) \cdot f_{messy} \cdot (dm_{grz} + ph_{grz} + dtn_{grz}) + MAX\left(0, assim_N - \frac{assim_C}{R^{Zp}_{c2n}}\right)$$

$$grz_{DIC} = (1 - f_{ingst}) \cdot f_{messy} \cdot (R^{Dm}_{c2n} \cdot dm_{grz} + R^{Ph}_{c2n} \cdot ph_{grz} + dtc_{grz}) + MAX(0, assim_C - assim_N \cdot R^{Zp}_{c2n})$$

- C:N of assimilatable gut contents calculated, compared to zooplankton C:N
- As much of assimilatable material as C:N will allow is assimilated, excess of C or N excreted as DIC or DIN
- Non-assimilatable material egested as detrital-N and detrital-C
- All grazed diatom silicate passes unchanged through gut, becomes detrital-Si

Mortality and closure

$$
\begin{aligned}
dm_{mort} &= \Pi^{Dm}_{mort} \cdot Dm^2 \\
dmsi_{mort} &= \Pi^{Dm}_{mort} \cdot Dm \cdot DmSi \\
ph_{mort} &= \Pi^{Ph}_{mort} \cdot Ph^2 & (Ph > ph_{min}) \\
&= 0 & (Ph < ph_{min}) \\
zp_{lin} &= \Pi^{Zp}_{lin} \cdot Zp \\
zp_{mort} &= \Pi^{Zp}_{mort} \cdot Zp^2
\end{aligned}
$$

- Zooplankton has quadratic loss-term (as do the autotrophs)
- For zooplankton this function represents “swarming” of their implicit predators (for autotrophs, viral attack)
- Two-thirds of zooplankton mortality goes to DIN/DIC, the rest to detritus (but only 1% of autotroph mortality goes to DIN/DIC)

Carbonate pump

$$ccfrmtn = R^{Ph}_{cc2pp} \cdot ph_{PP}$$

$$\begin{aligned} xprt_{cc} &= \sum_n (ccfrmtn_n \cdot \Delta_n) \\ ccdsltn &= \frac{xprt_{cc}}{\Delta_{dsl}} \qquad (\,valid\ lyrs\,) \\ &= 0 \qquad (\,other\ lyrs\,) \\ crbnt &= ccdsltn - ccfrmtn \end{aligned}$$

- CaCO3 is produced in a fixed ratio to organic production
- In Diat-HadOCC only production by non-diatoms is considered, and fixed ratio has been adjusted to globally compensate
- CaCO3 does not sink with organic detritus, but is instantly moved to below the prescribed lysocline and re-dissolved evenly between that and the sea-floor
- If sea-floor is shallower than lysocline, it is re-dissolved in the bottom layer

Detritus: sinking & remin

- Explicit slow-sinking detritus (10m/d)
- HadOCC: Fixed C:N ratio (7.5 cf 6.625 in phyto, 5.625 in zoop)
- Diat-HadOCC: separate state variables for N, C and Si
- For det-N and det-C: specific remineralisation rate varies as reciprocal of depth (gives Martin-style power-law), but is "capped"
- Det-C: constant specific remin rate

Detritus: at the sea-floor

- All detrital material reaching the sea-floor is instantly remineralised to DIN, DIC, or Si
- Newly-remineralised material spread evenly over lowest three layers
- (Sinking diatoms that hit the sea-floor die instantly, becoming det-N and det-C in the bottom layer; their diatom-silicate becomes det-Si in bottom layer)

OBGC interactions with the atmosphere

- Surface ocean pCO2 calculated using published equilibrium constants
- Piston velocity from Wanninkhof (1992)
- Surface DMS calculated from model (non-diatom) chlorophyll and MLD using Simo & Dachs (2002)
- Iron supplied by dust deposition; constant fraction (by weight) assumed to be iron

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Questions and answers