How coarse can ocean resolution be?

Helene Hewitt, Pat Hyder, Pierre Mathiot, Tim Graham, Dave Storkey, Malcolm Roberts

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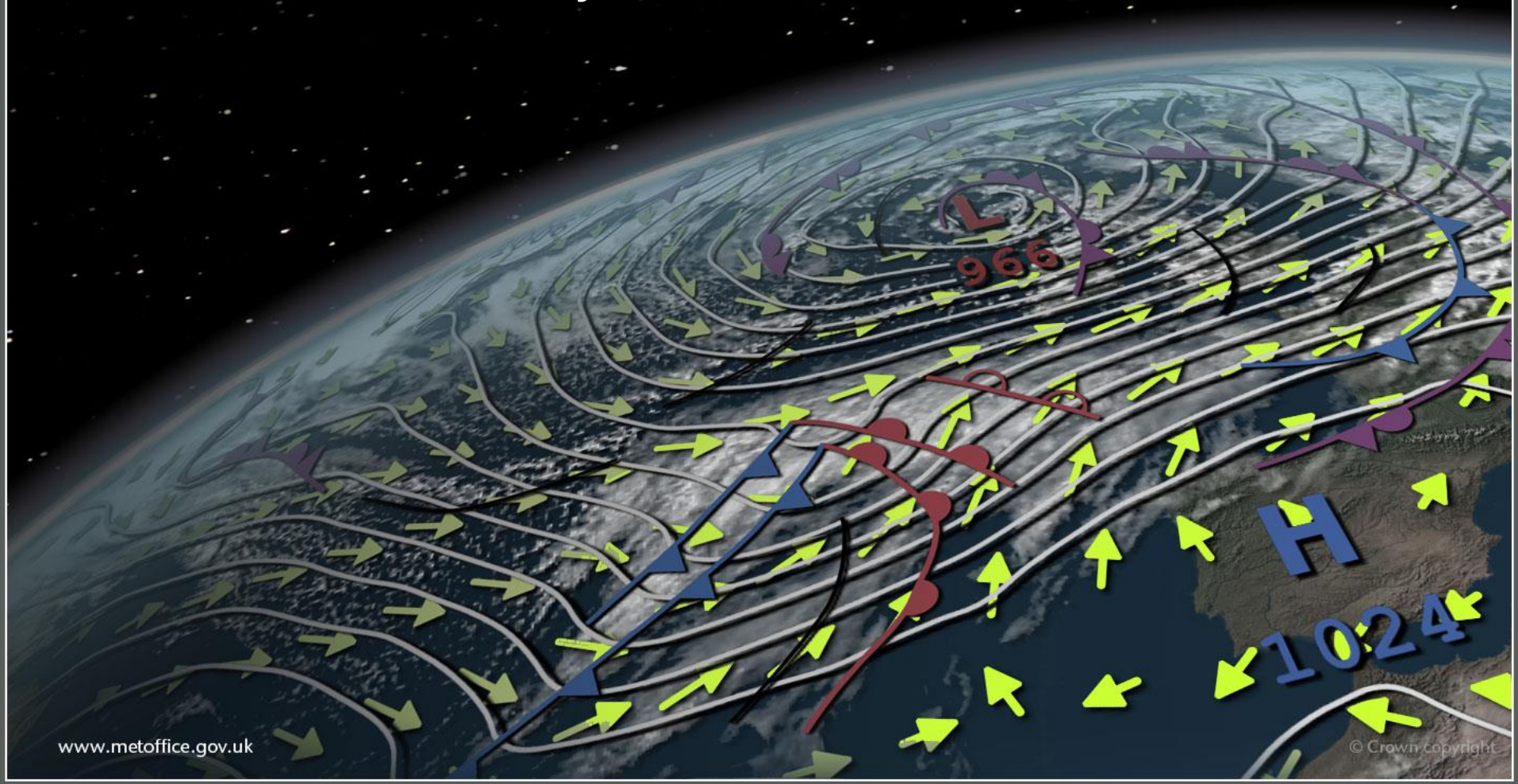


How coarse can ocean resolution be?

- How do you choose the appropriate ocean resolution for your particular application?

- What compromises are you making with your choice of ocean resolution?

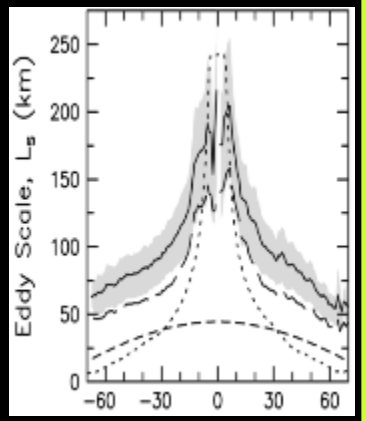
Outline

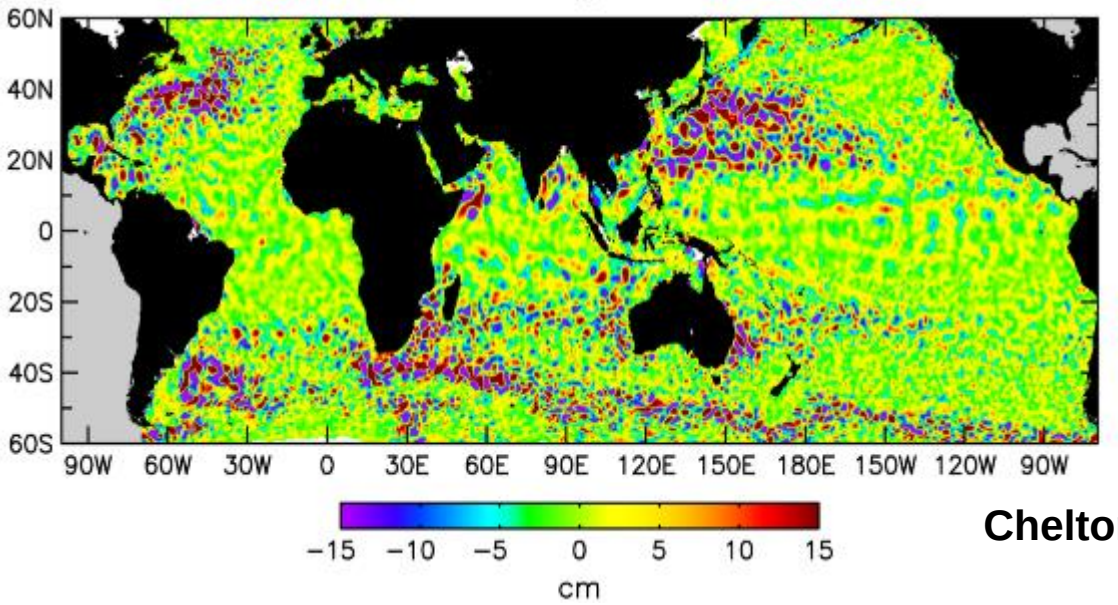
Introduction
- Resolving the Rossby radius
- Parameterisation considerations

Benefits of resolution
- Energetics
- Heat Budgets
- Tropics
- Thermohaline circulation
- Coupling

Conclusions
- Choices for your application
- Cost considerations
- Traceable model hierarchy

Observations of mesoscale eddies





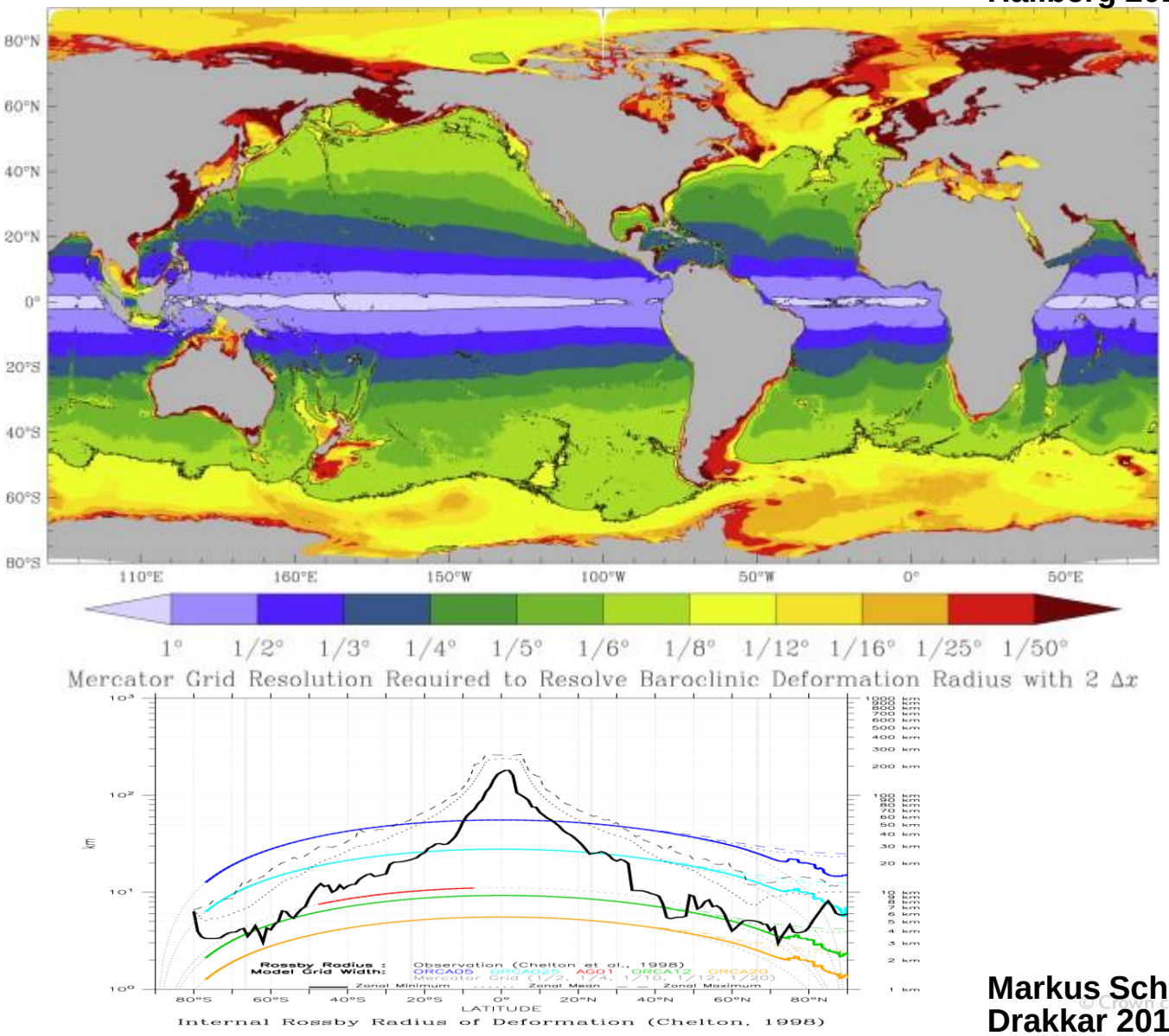
Chelton et al., 2011

- Coherent vortices, radius of about 50-100 km
- Generated by baroclinic and barotropic instabilities
- ~215,000 eddies with 4 weeks or longer lifetime over 20 years (Chelton et al., 2011)
- They are everywhere in the ocean!

Resolution to resolve Rossby radius

Met Office
Hadley Centre

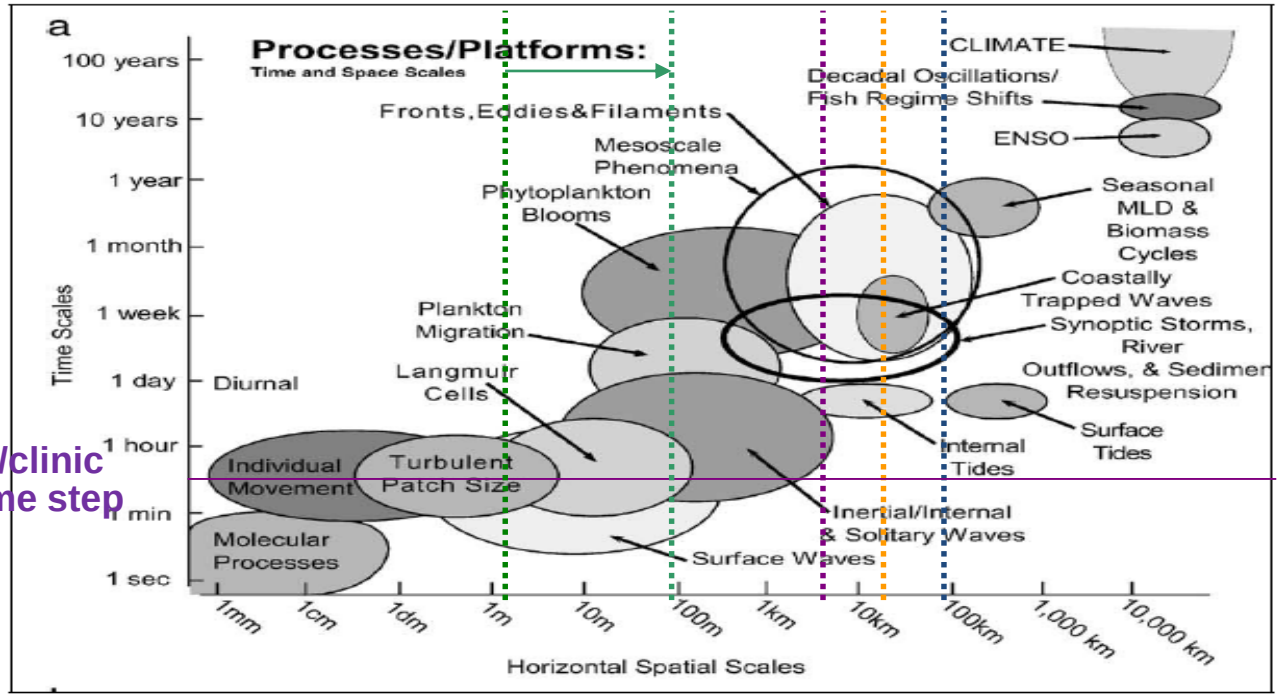
Hallberg 2013



Markus Scheinert, Drakkar 2012

Space-time characteristics of ocean processes

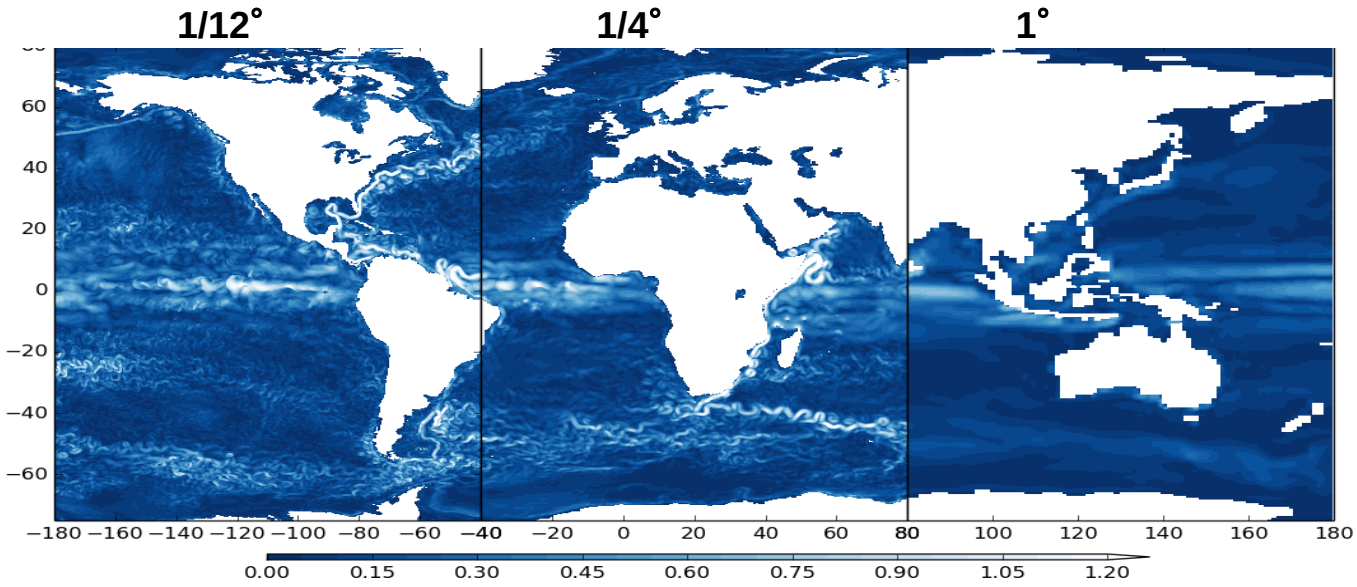
Vertical resolution 1/12º 1/4º 1º



B/clinic Time step

From Dickey (2003)

Spanning the eddy regime



Eddy resolving

No GM, low isopycnal mixing

Eddy permitting

How to parameterise?

GM? Isopycnal mixing?

Scale selective?

Eddy parameterising

GM and isopycnal mixing

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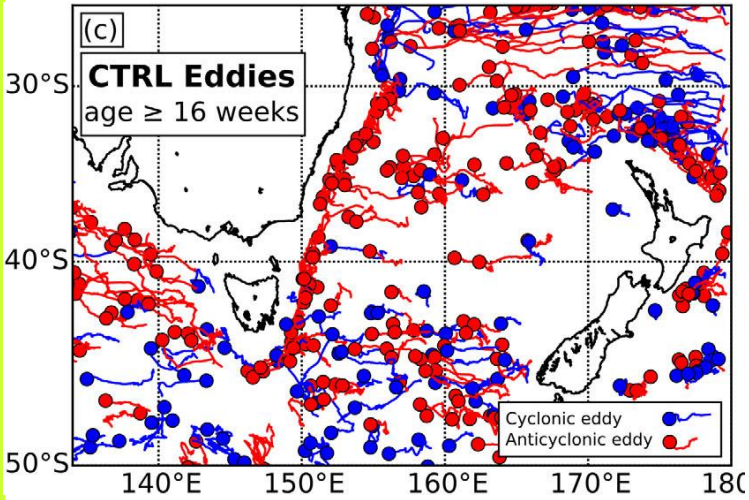
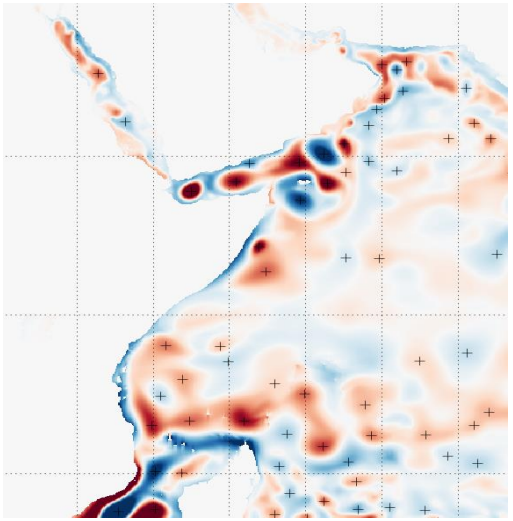
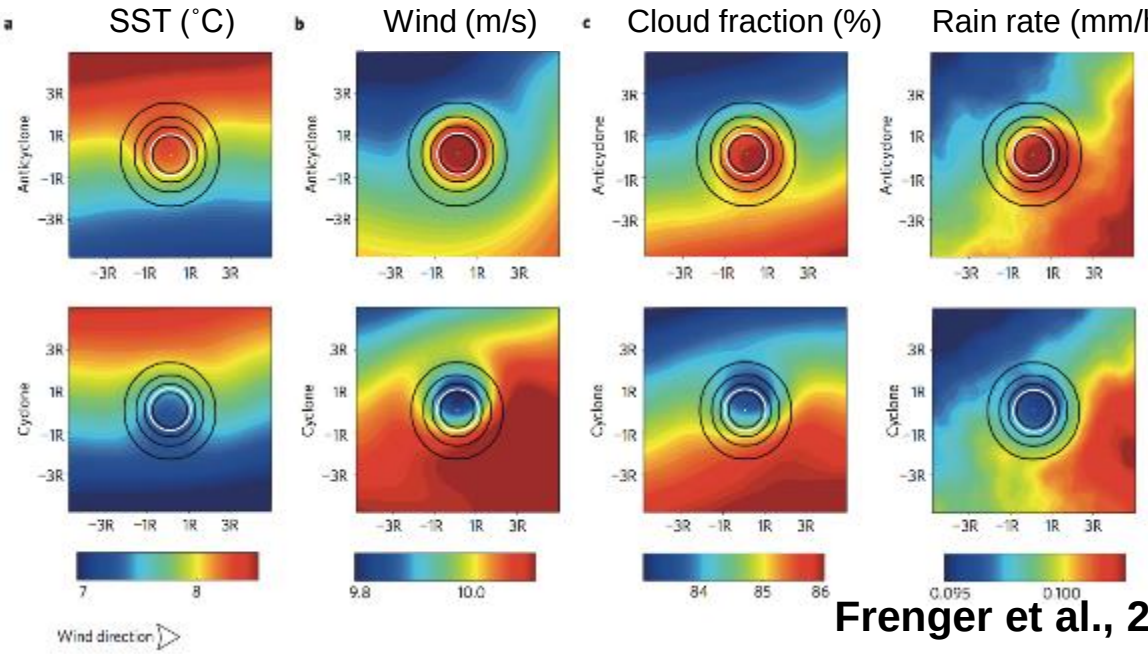
Eddies at ~1/10°



Oliver et al., 2015



Pierre Mathiot



Frenger et al., 2013

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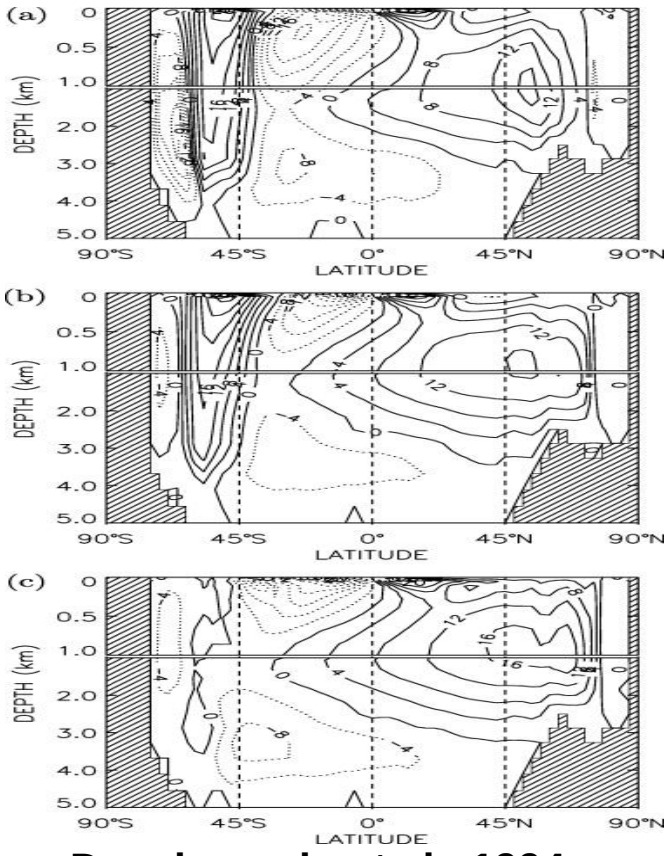
Parameterising eddies

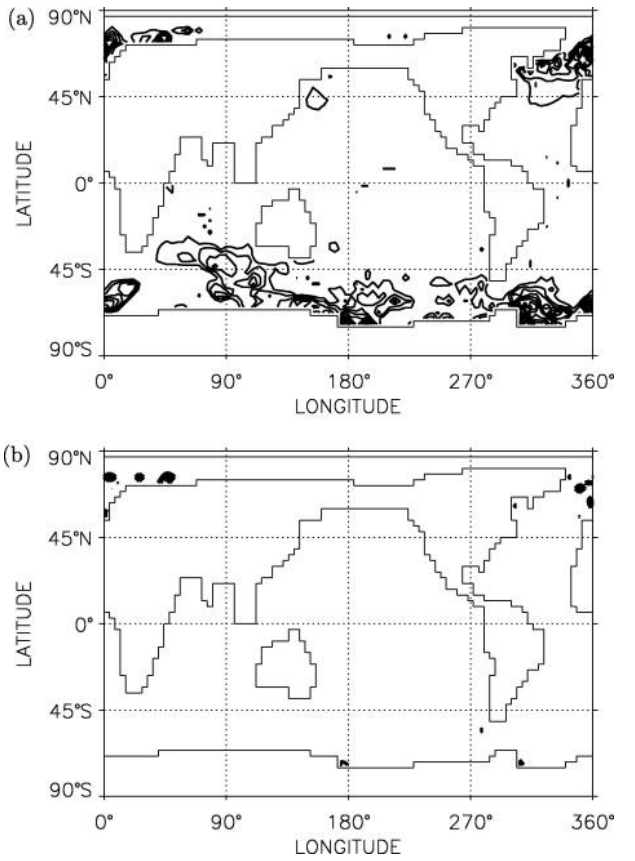
$$\frac{\partial}{\partial t} h_\rho + \nabla.(\mathbf{u} h_\rho) = \nabla.(\kappa \nabla h)_\rho$$

$$u^* = -\frac{\kappa}{\bar{h}} \nabla_\rho \bar{h}$$

Thickness diffusion

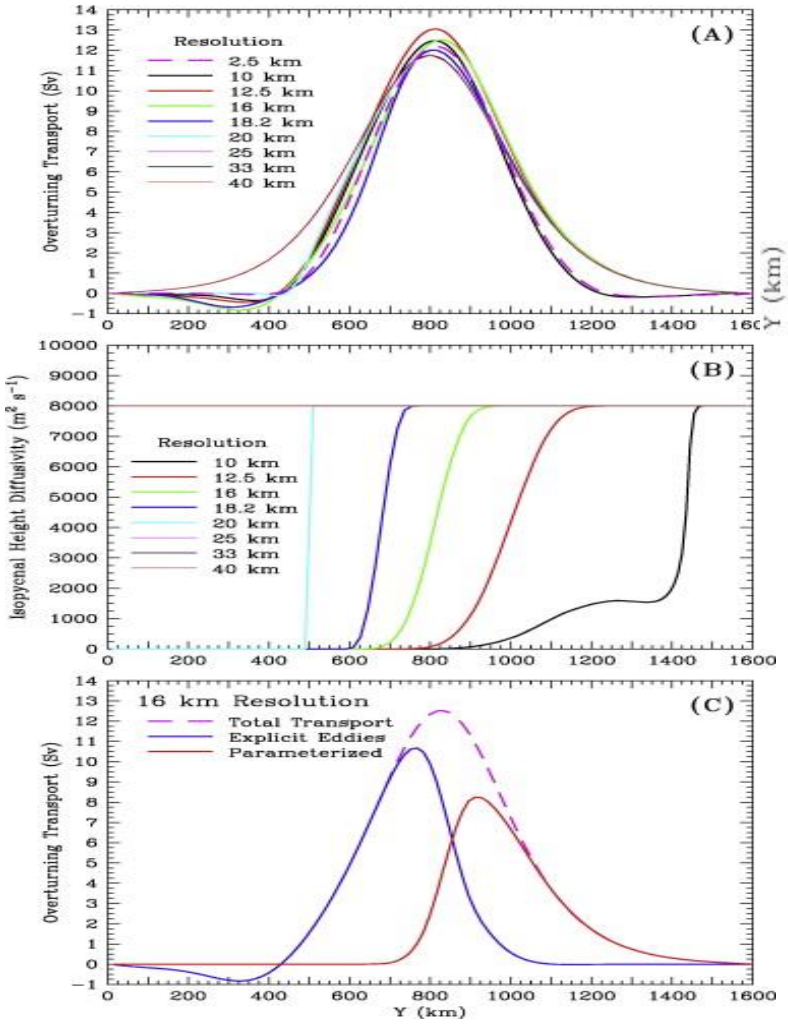


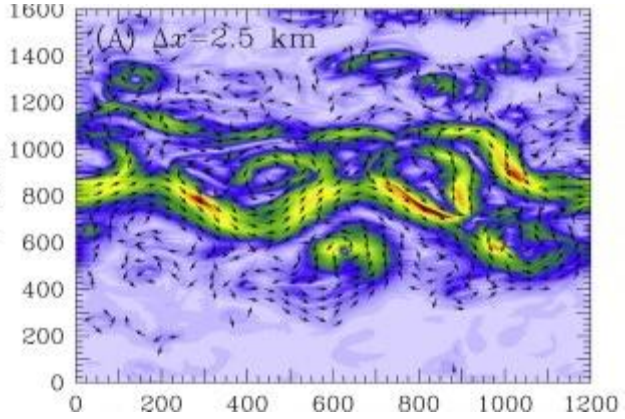
Danabasoglu et al., 1994



Gent & McWilliams, 1990

Parameterising as a function of resolution





Hallberg 2013

Switch on GM when Rossby radius < 2*dy

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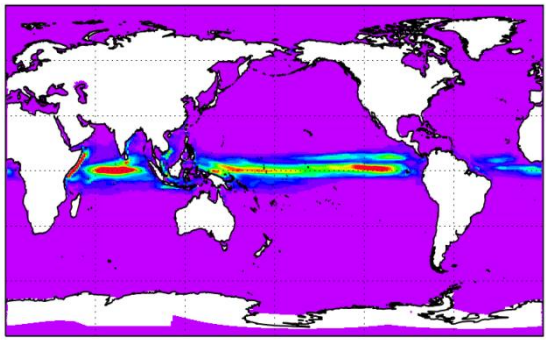
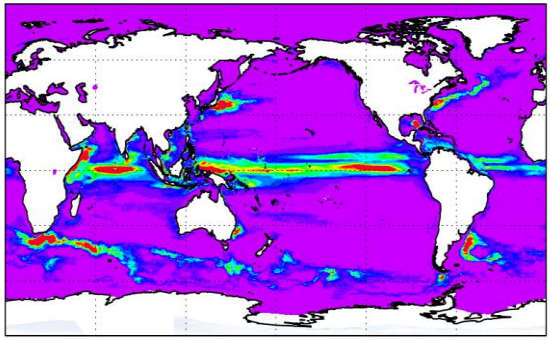
Eddy kinetic energy

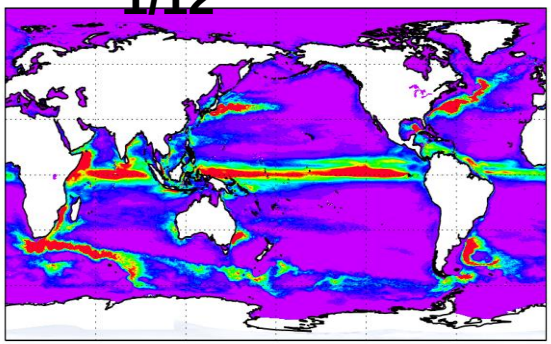
1°



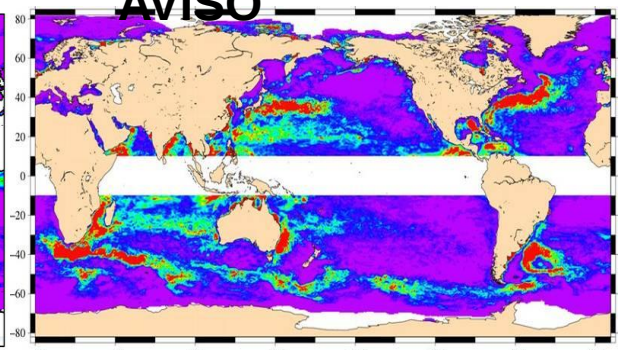
1/4°

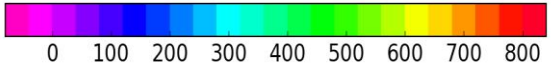


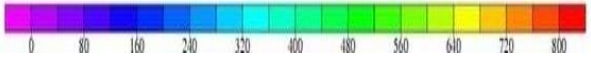
1/12°



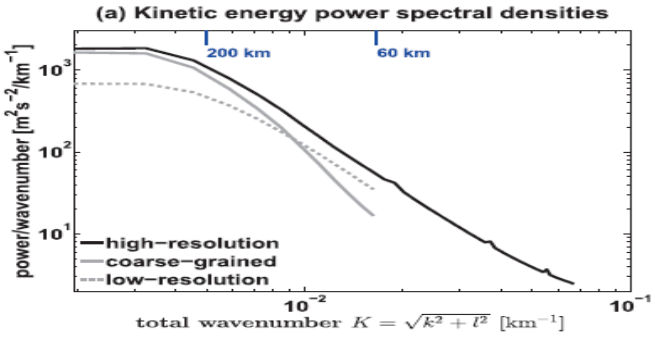
AVISO







Pierre Mathiot



Mana and Zanna, 2013

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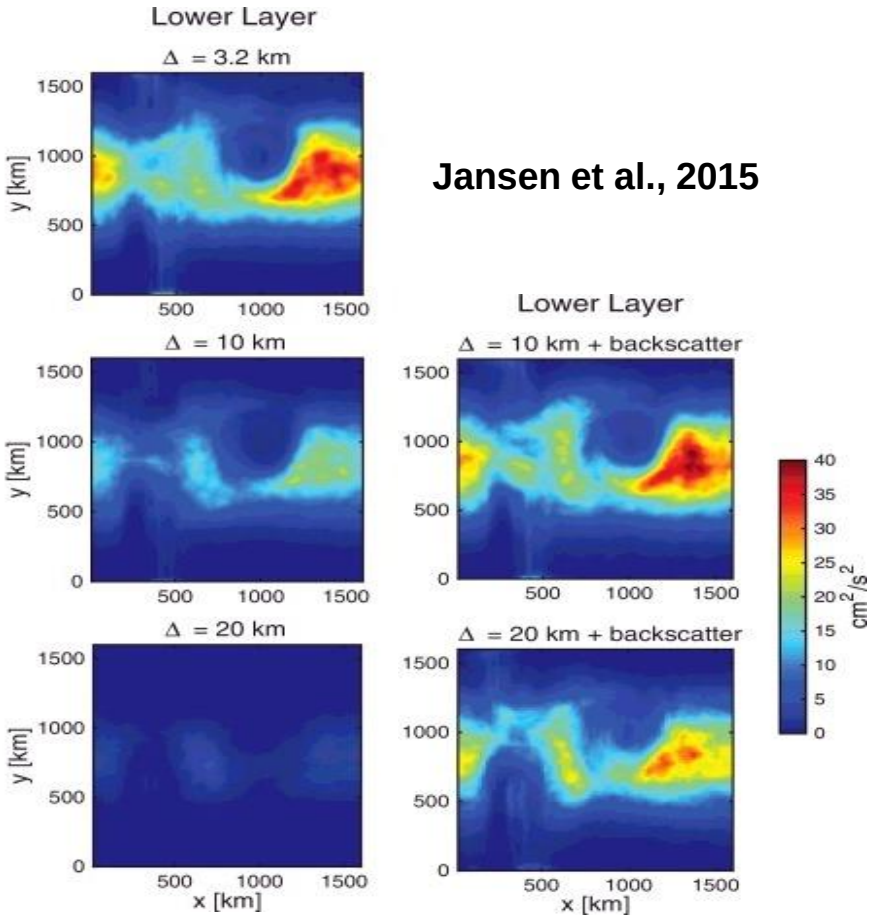
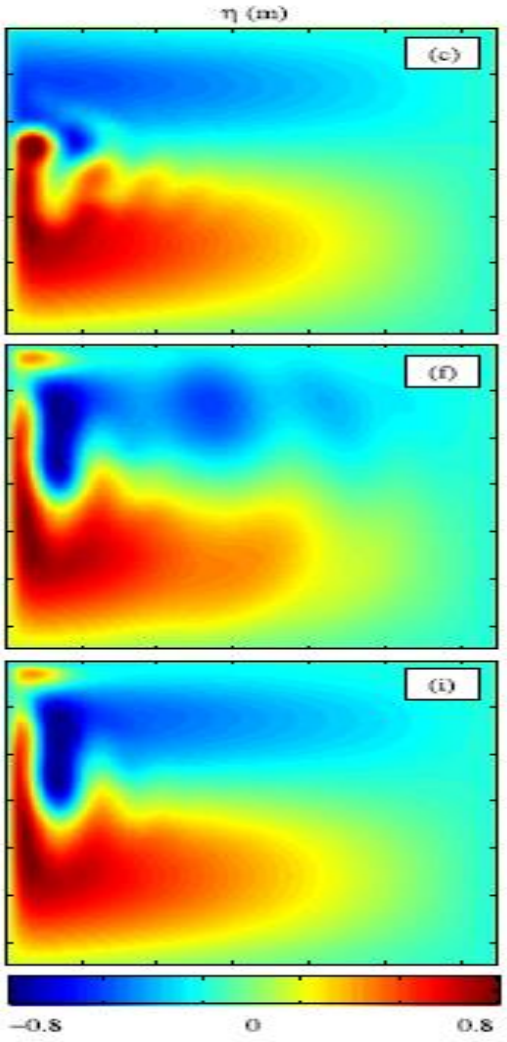
Backscatter parameterisations



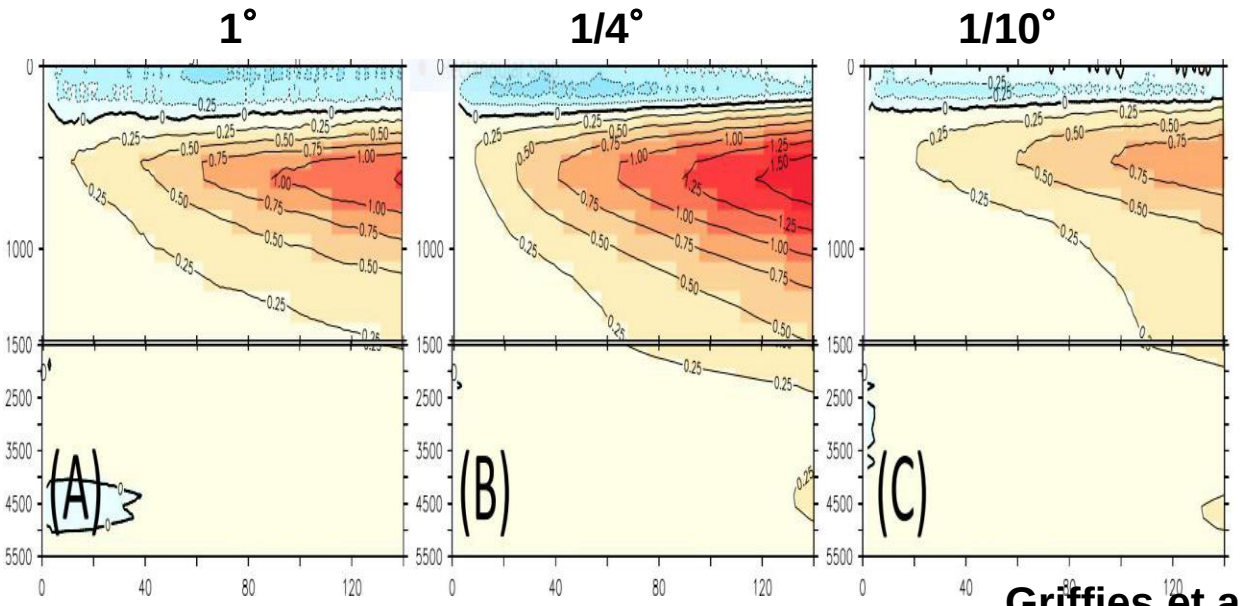
Jansen et al., 2015



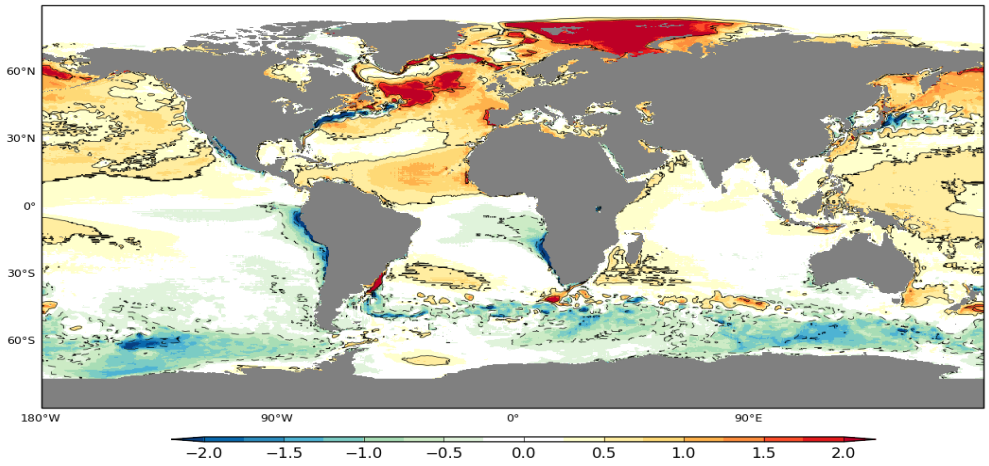
Cooper and Zanna, 2015

Backscatter parameterisation ideas are growing and look promising for latitudes where Rossby radius not resolved

Temperature drifts



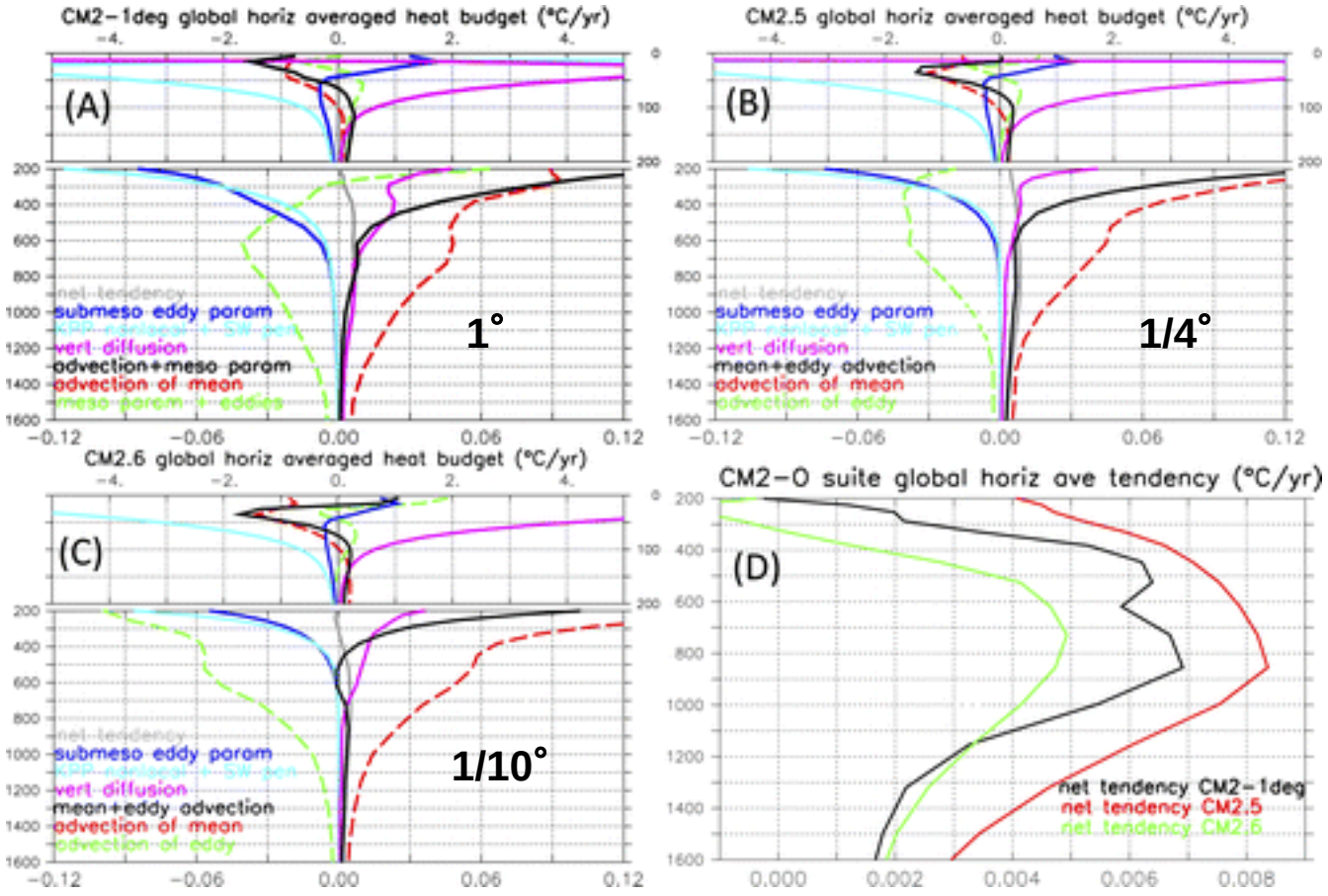
Griffies et al., 2015



SST error change 1/12 – 1/4

Hewitt et al., 2016

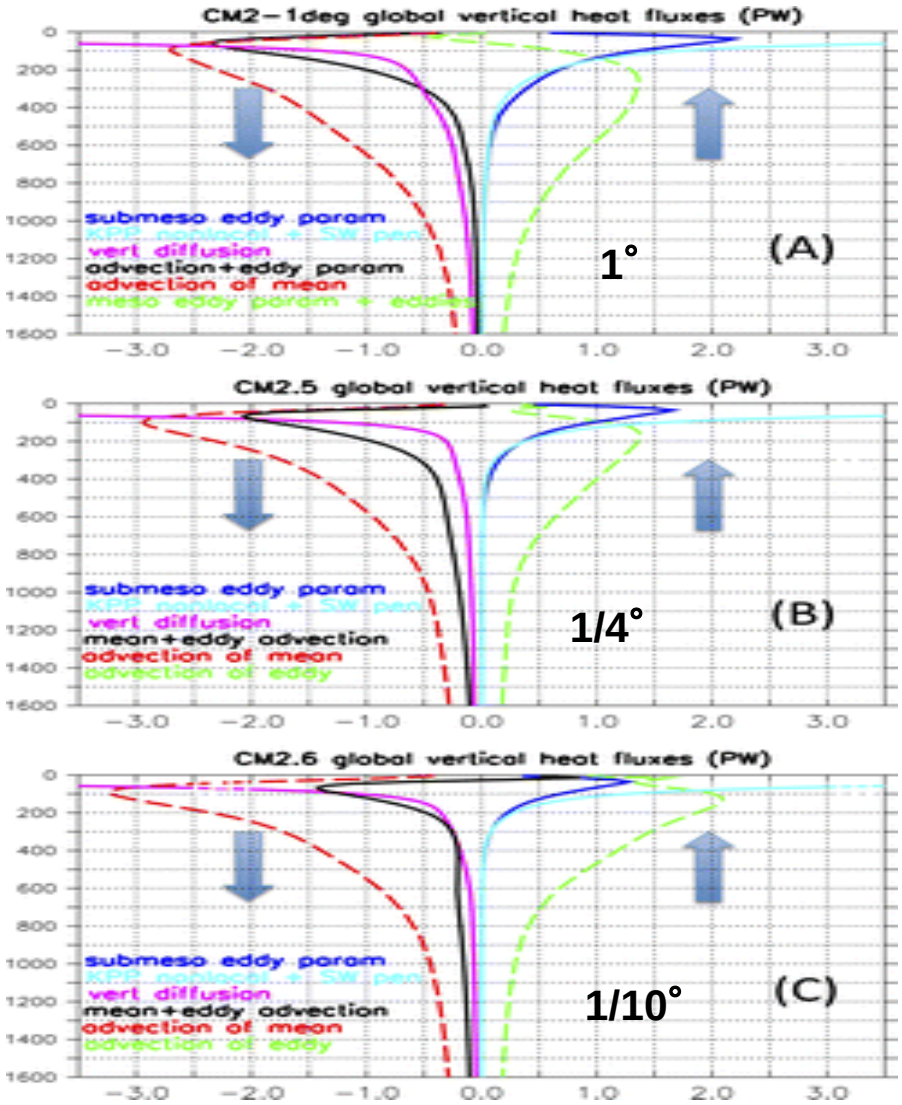
Eddies in heat budgets



Griffies et al., 2015

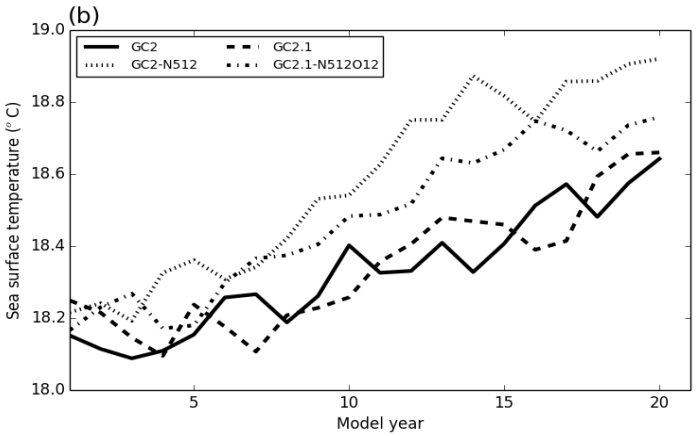
- Eddy parameterisations do approximately the right thing
- Drifts are residual of large cancellations!

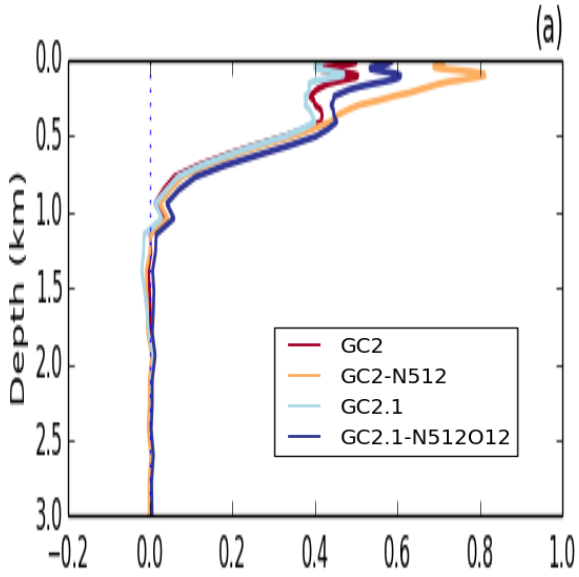
Eddies transport heat upwards



Griffies et al., 2015

Mean advection role



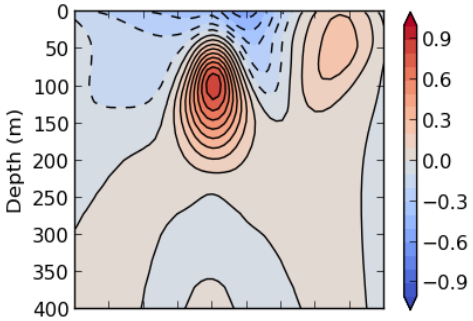


Model	Net TOA (W/m^2)	Global mean SST error (K)	Maximum overturning at 30°S (Sv)	Maximum overturning at 24°N (Sv)	Net transport from overflows (Sv)
Observations	0.85				
GC2	1.61	0.25	13.7	14.6	4.0 (0.24)
GC2-N512	1.79	0.60	14.3	14.9	3.9 (0.28)
GC2.1	1.64	0.29	14.3	16.4	4.7 (0.26)
GC2.1-N512O12	2.02	0.44	17.5	17.7	5.9 (0.42)

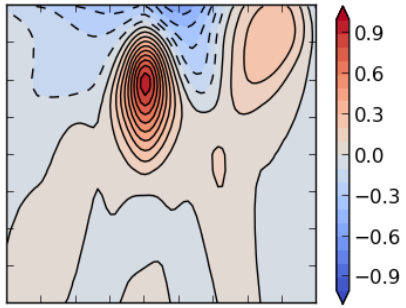
Hewitt et al., 2016

Equatorial currents

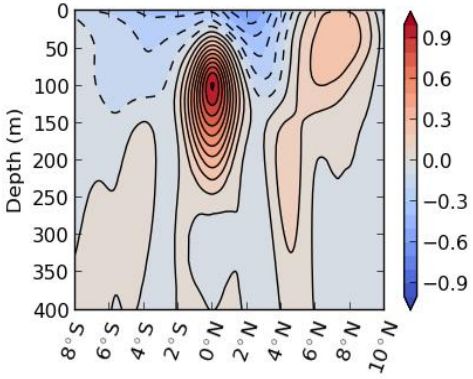
1°



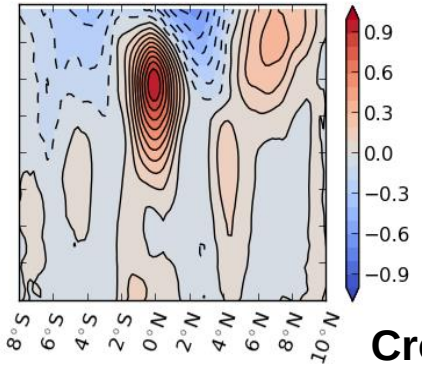
1/4°



1/12°



Observations

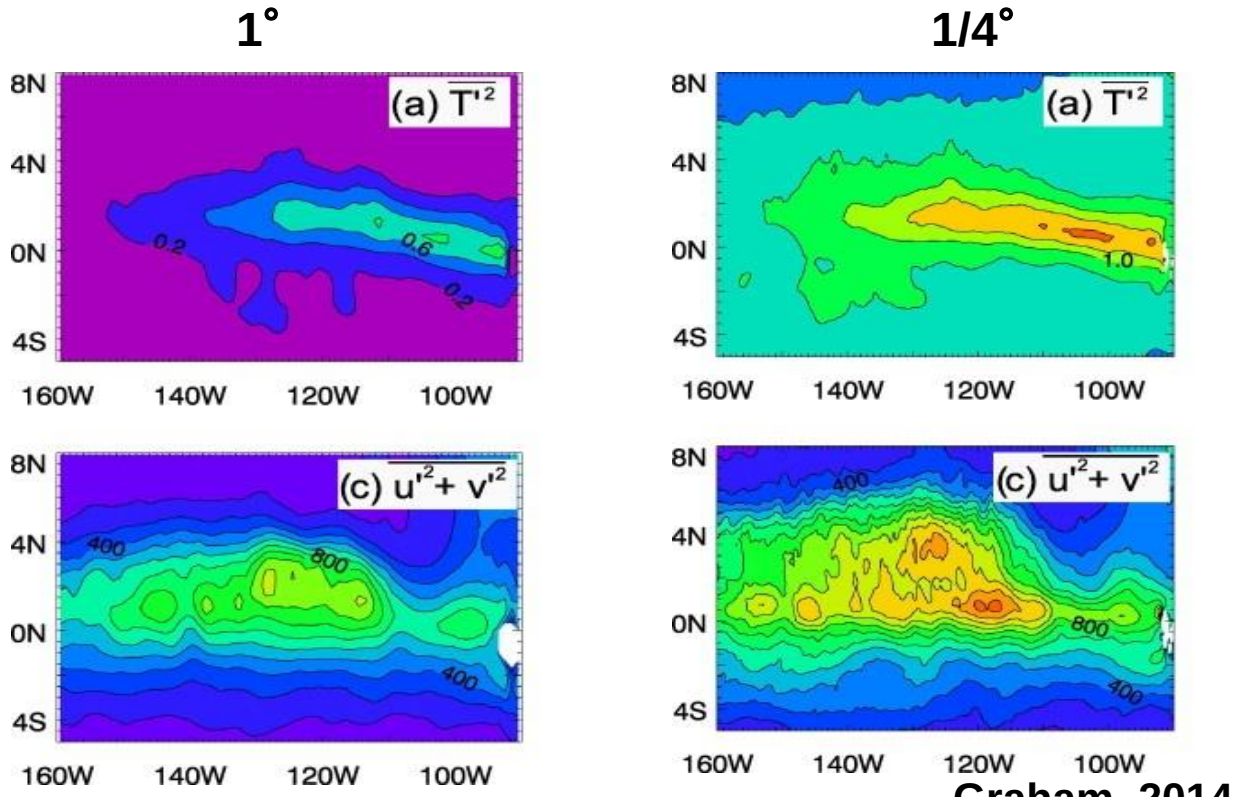


Crocker and Graham

Ocean model resolution will have little impact on El Nino once Kelvin and Rossby waves resolved

Guilyardi et al., 2004

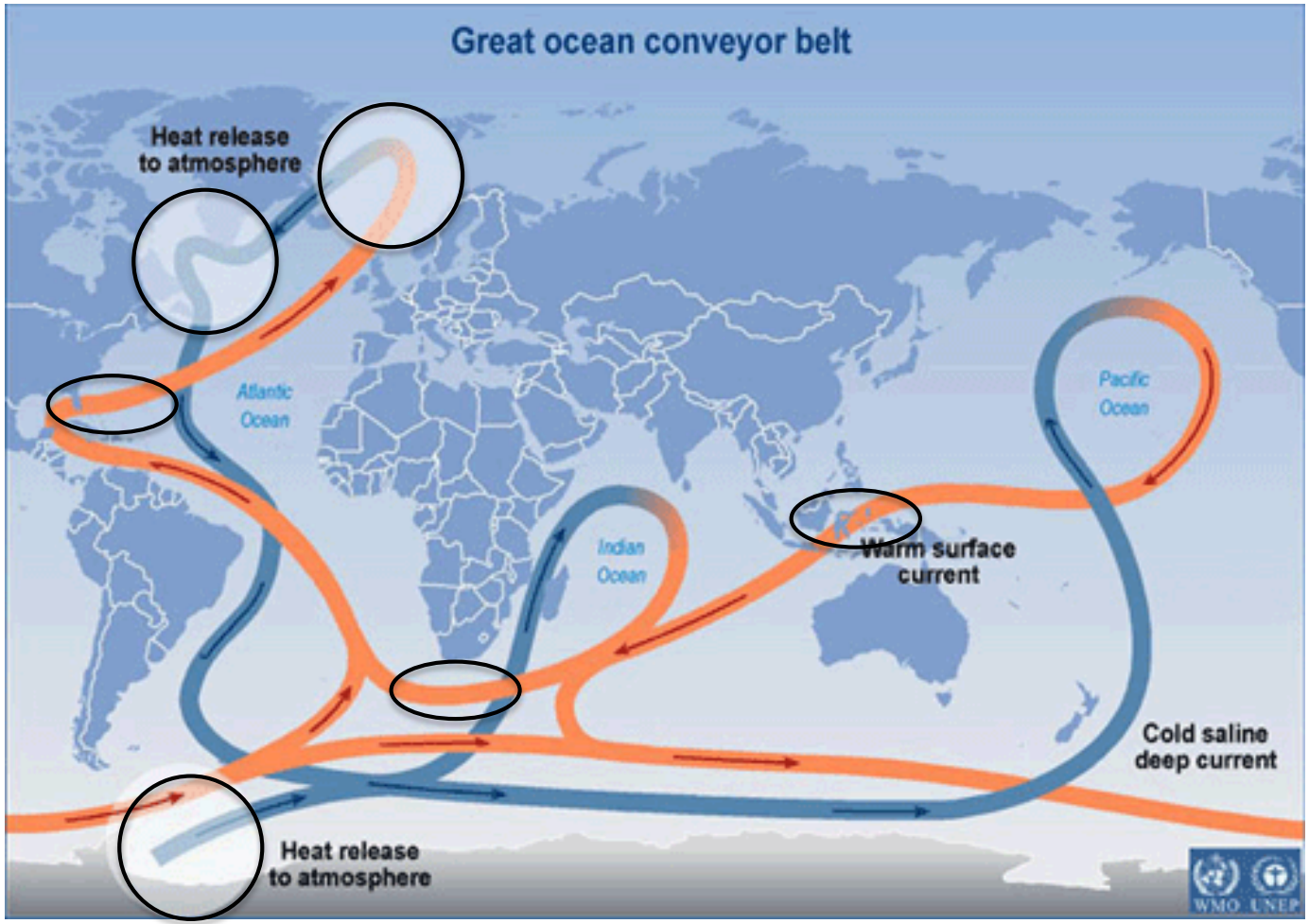
Role of Tropical Instability Waves



Graham, 2014

Heating by TIWs ~75% greater at high resolution during La Nina → reduced cold bias and enhanced asymmetry in ENSO

Key features of the global ocean circulation



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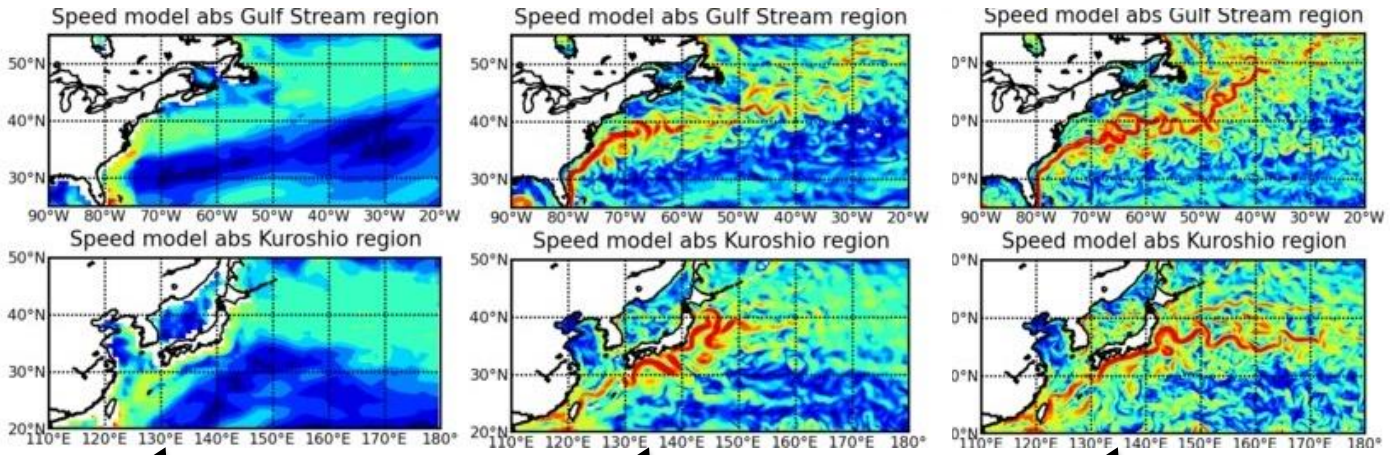
Gulf Stream and Kuroshio

Met Office
Hadley Centre

1˚ | 1/4˚ | 1/12˚

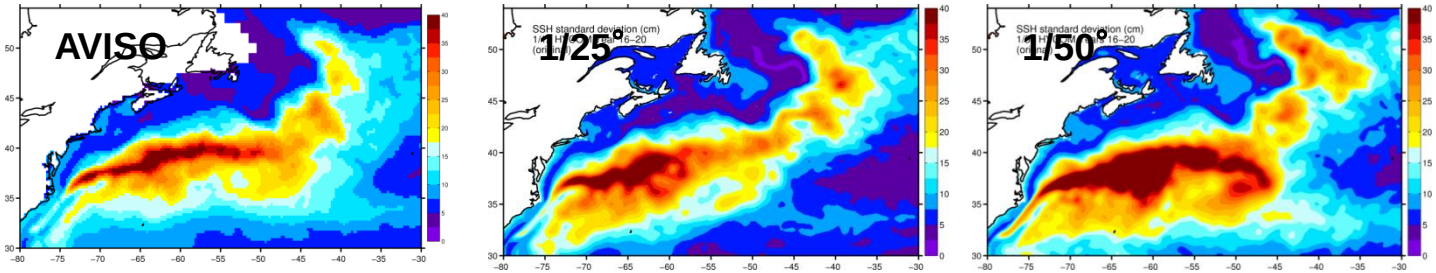


Pat Hyder

Diffusive rather than inertial boundary layers

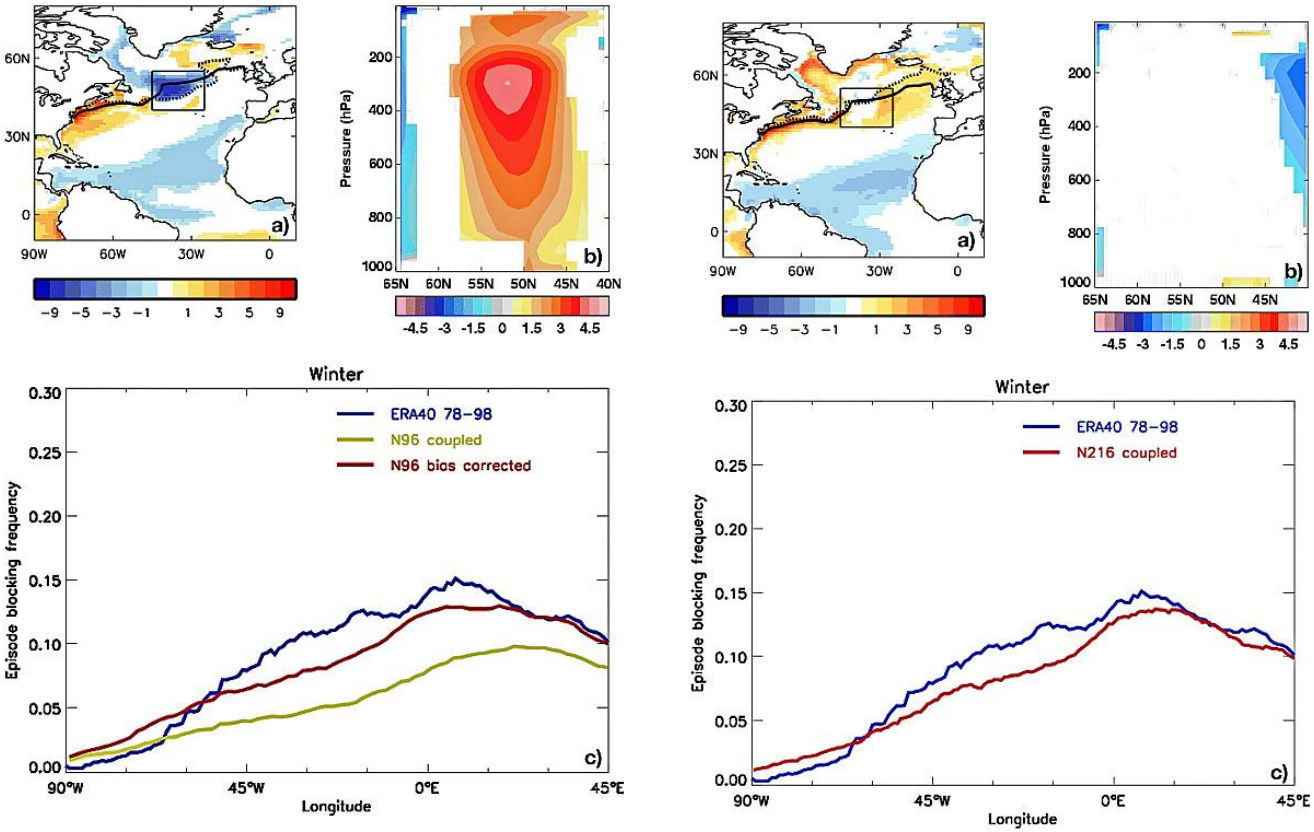
Don't adequately resolve extension region

Is even this resolution sufficient?



Eric Chassignet

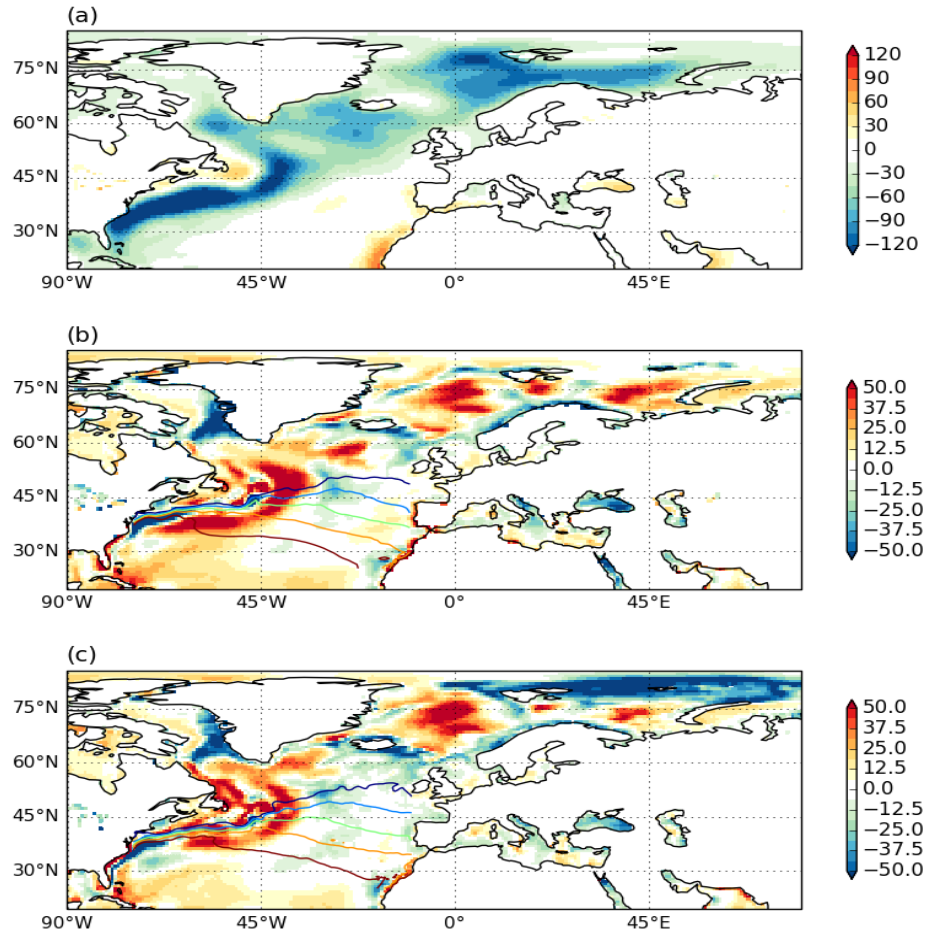
Improved winter blocking at eddy permitting resolution



Improved current path likely due to increased communication between surface and deep ocean (and may not be for entirely correct reasons)

Scaife et al., 2011

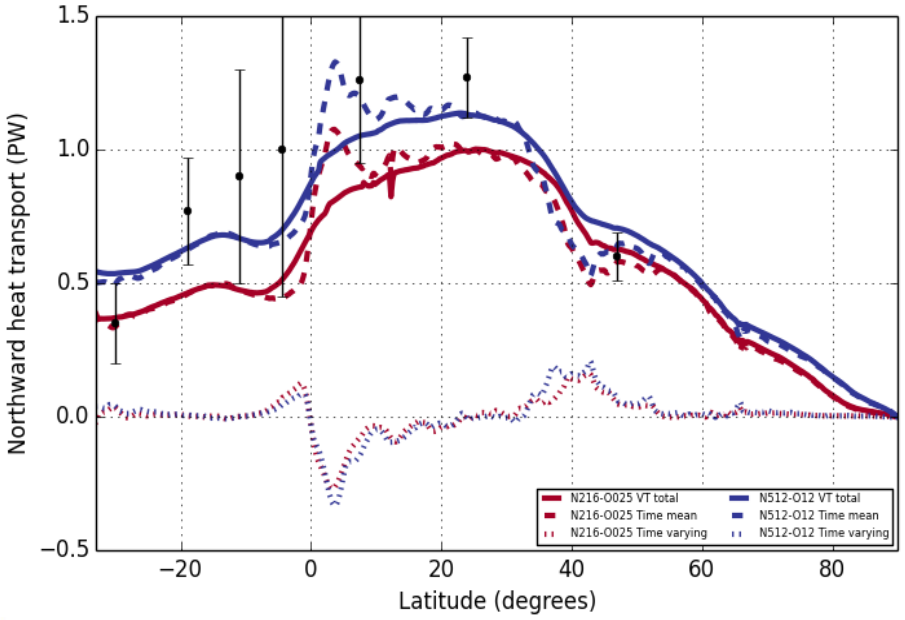
Resolution affects the mean state

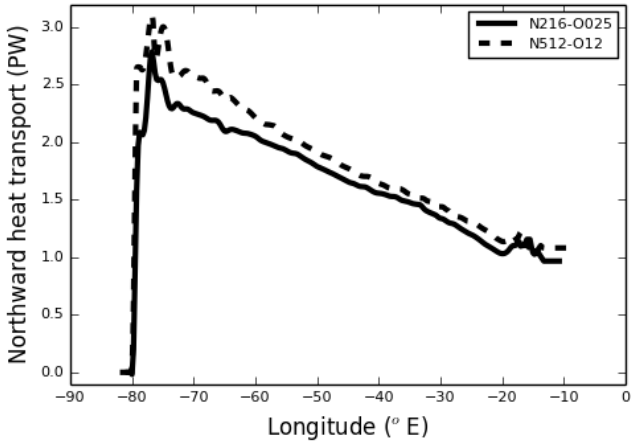


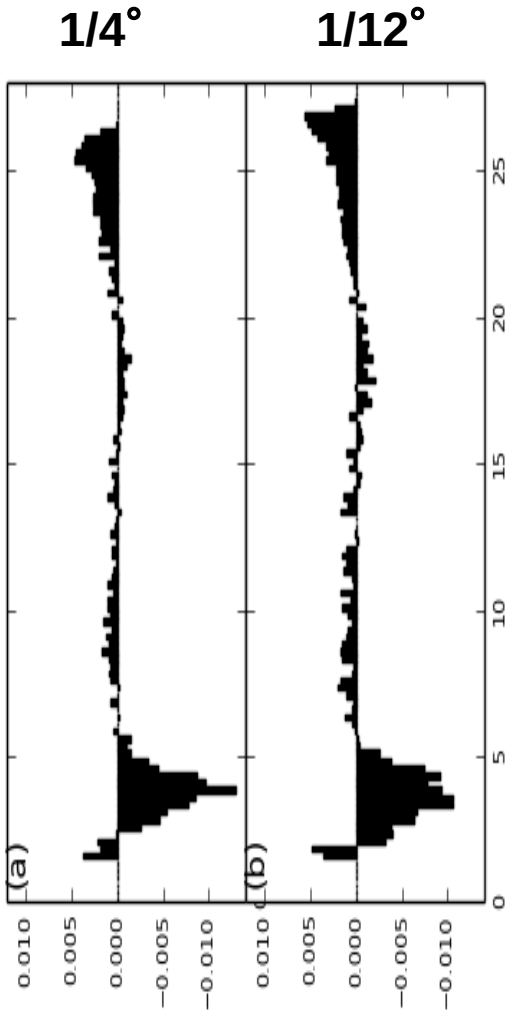
Heat flux error reduction linked to SSTs in Gulf Stream

Roberts et al., submitted

Resolution changes heat transport

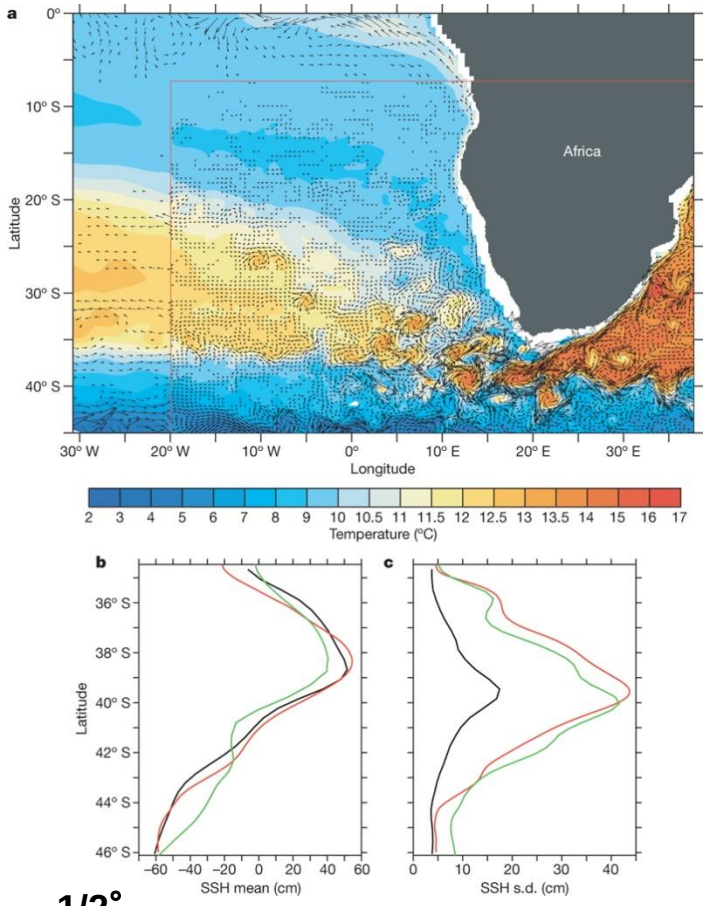






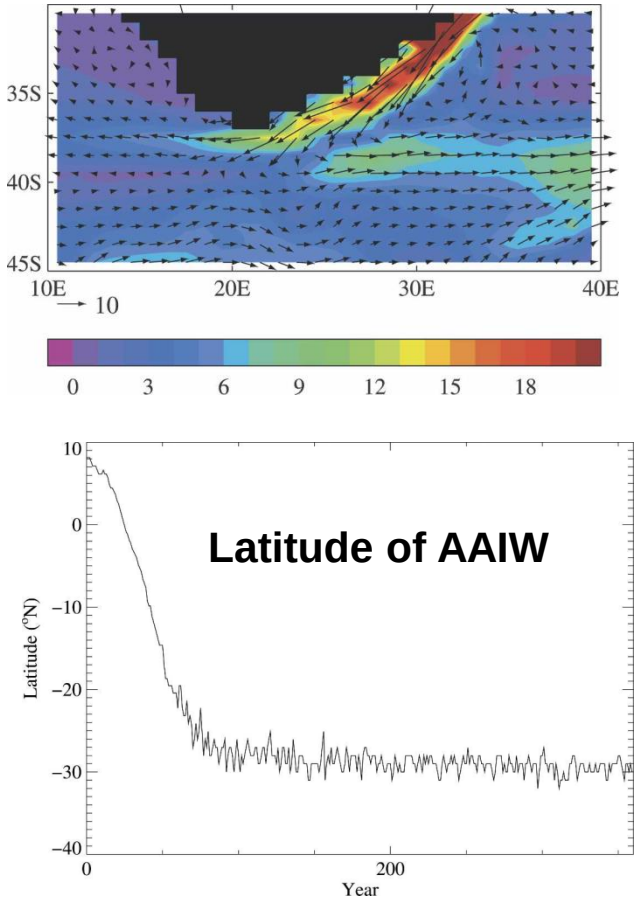
Roberts et al., submitted

Agulhas current is important



1/2°
1/10°
AVISO

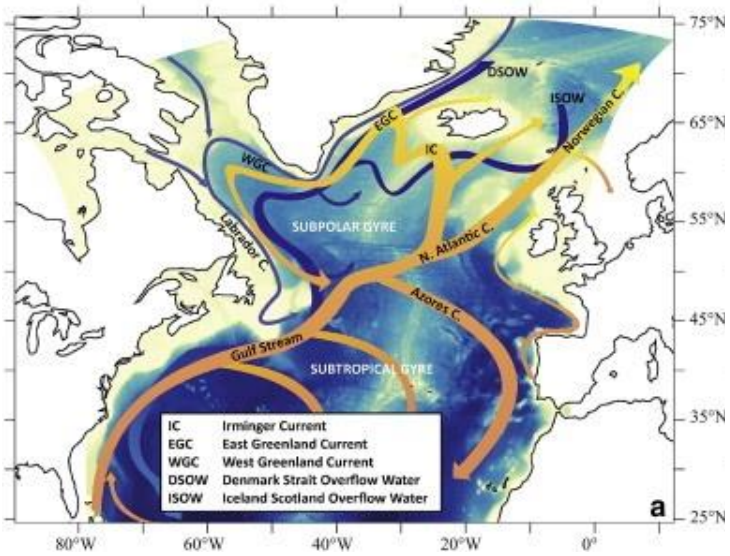
Biastoch et al., 2008



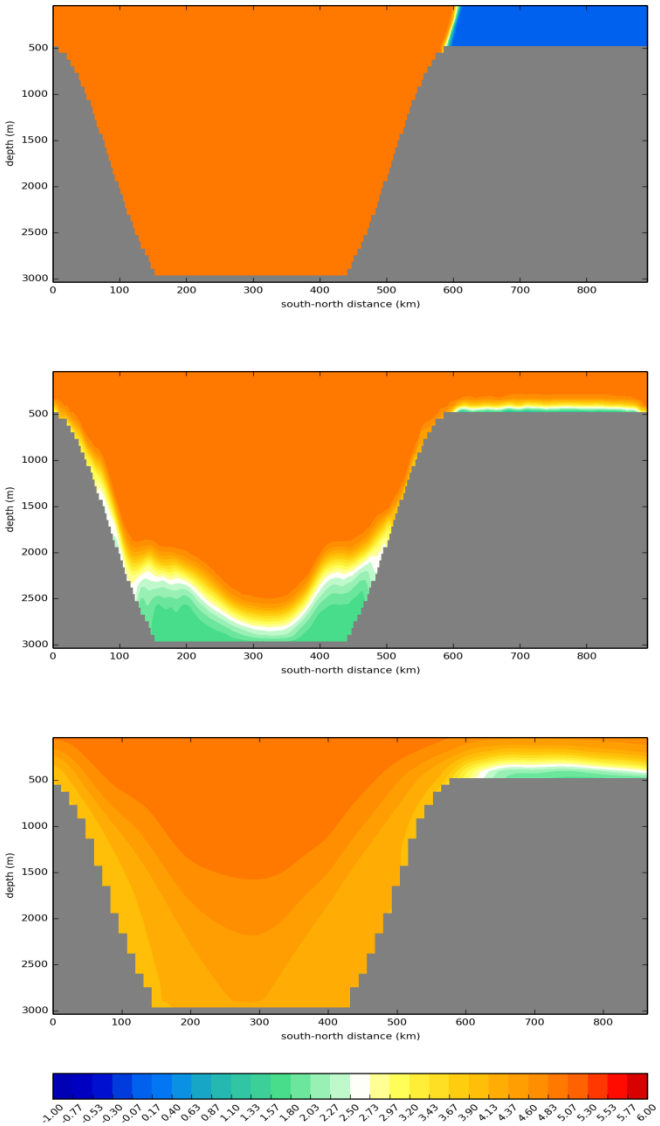
Banks et al., 2007

Representing the Agulhas is key to the long term properties of a climate model

Overflows need resolution



Marzocchi et al., 2015



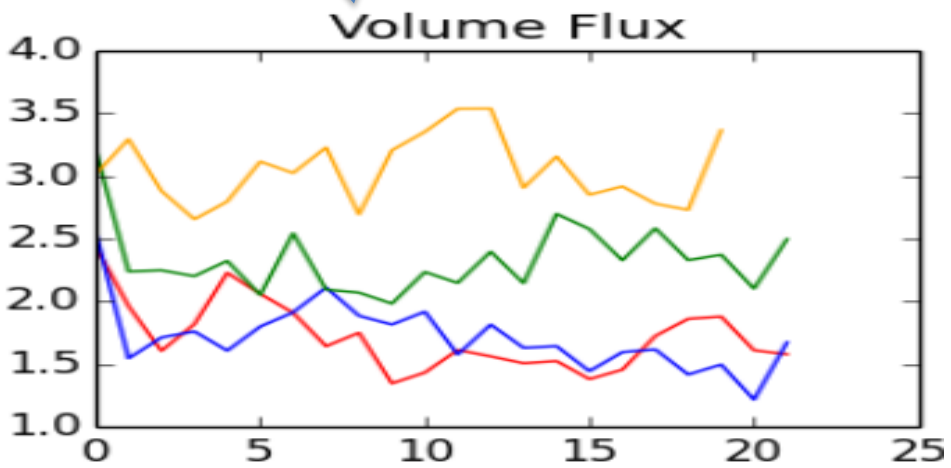
Horizontal: 3-5km
Vertical: 30-50m

Winton et al. (1998)

Dave Storkey

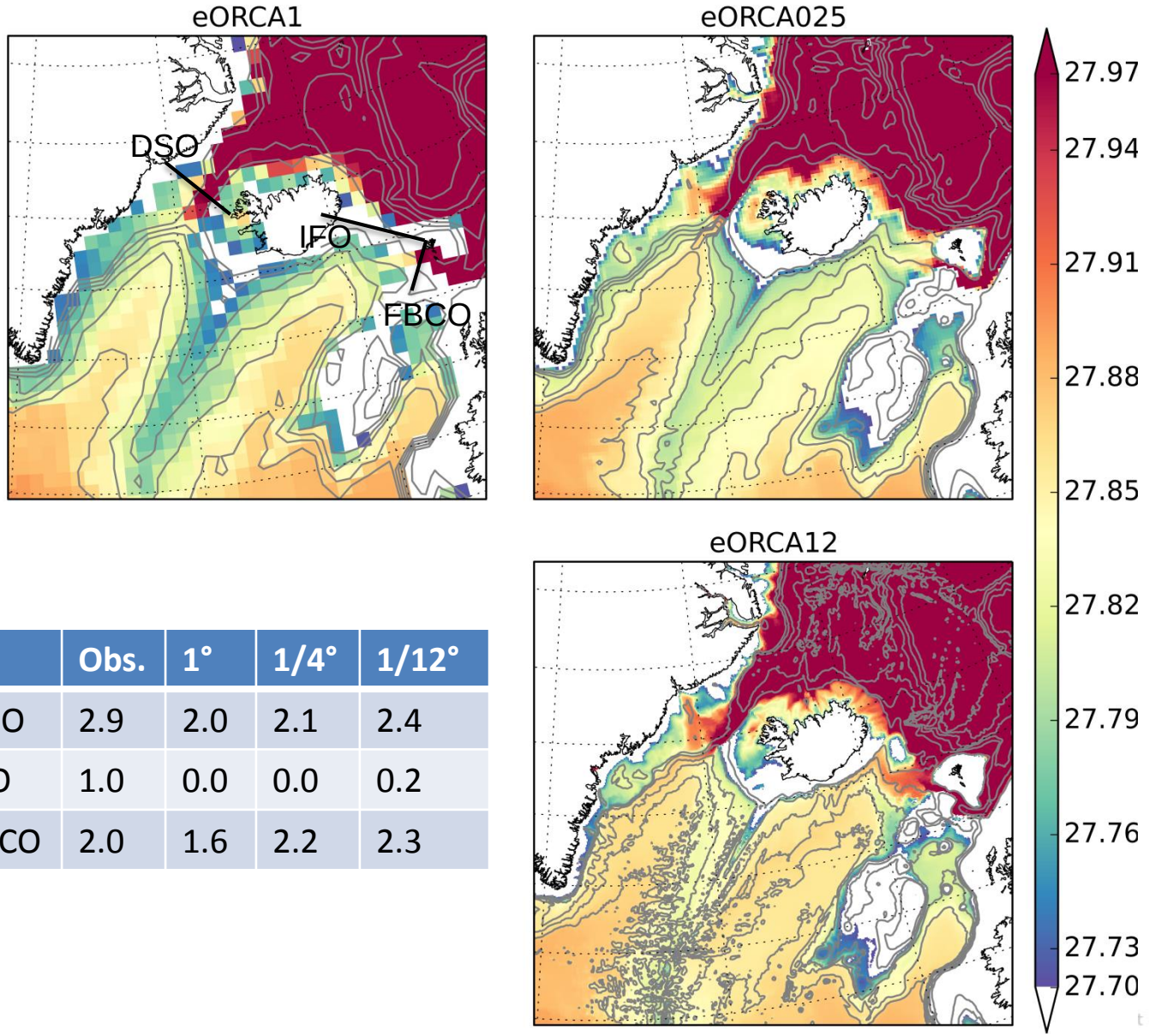
Overflows

	Observations	Eddy permitting	Eddy-resolving
Denmark Straits	2.9 Sv	1.7 Sv	3 Sv
Iceland-Faroe	1 Sv	0.1 Sv	0.7 Sv
Faroe-Shetland	2 Sv	2.4 Sv	2.1 Sv
Greenland-Iceland-Scotland	5.6 Sv	4.2 Sv	5.8 Sv



Hewitt et al., 2016

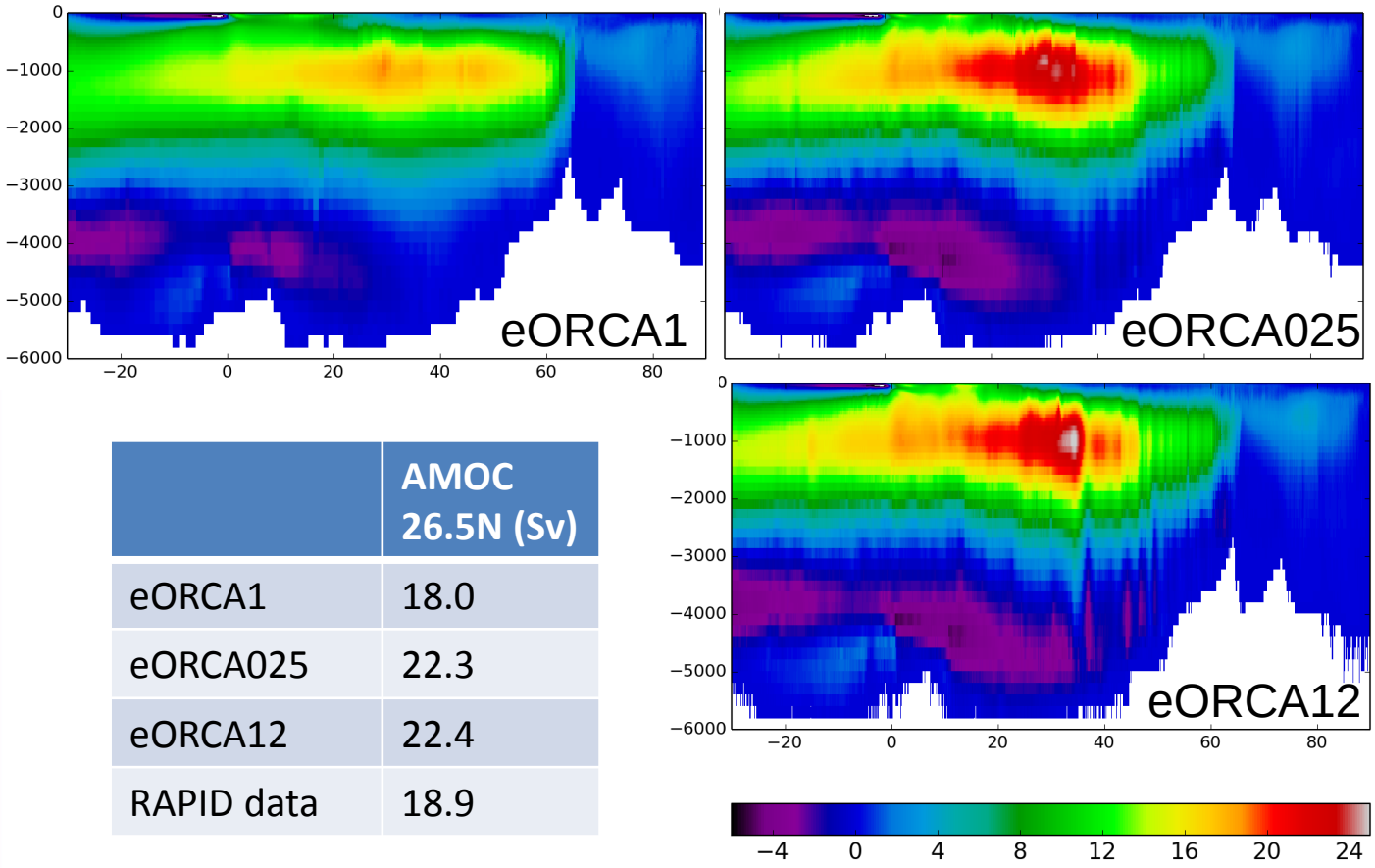
Topographic control at overflows



	Obs.	1°	1/4°	1/12°
DSO	2.9	2.0	2.1	2.4
IFO	1.0	0.0	0.0	0.2
FBCO	2.0	1.6	2.2	2.3

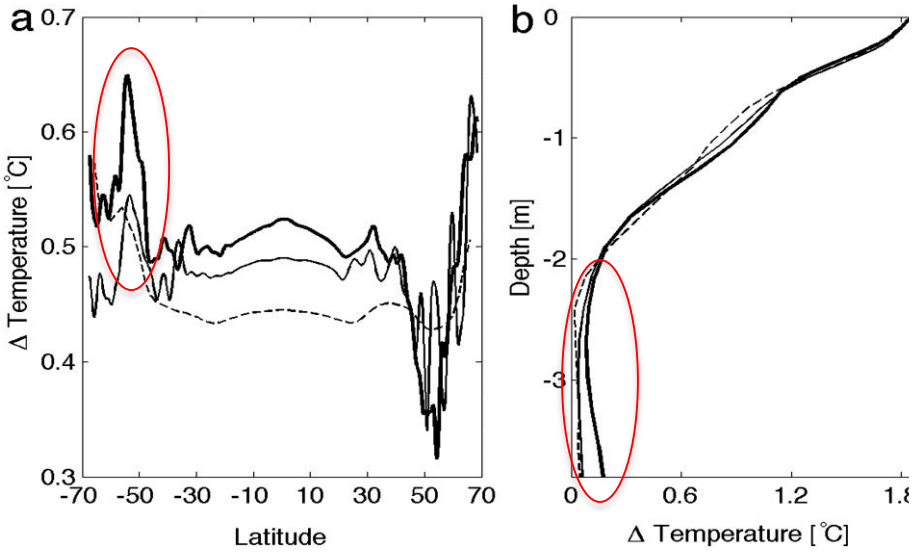
AMOC across resolutions

AMOC stronger at ‘eddy resolving’ resolution

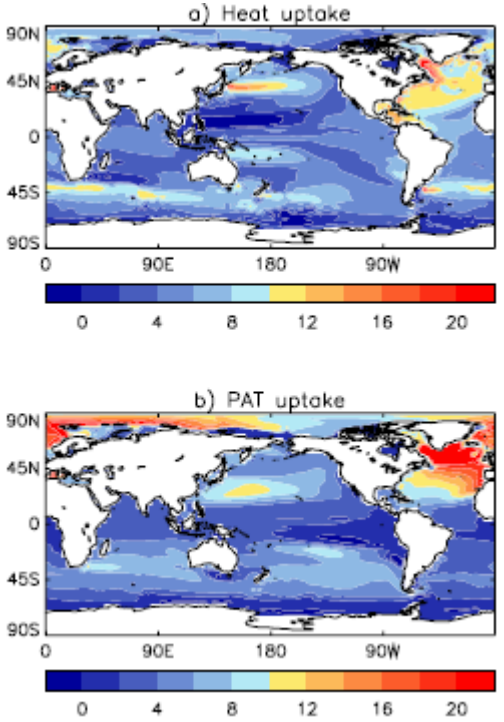


	AMOC 26.5N (Sv)
eORCA1	18.0
eORCA025	22.3
eORCA12	22.4
RAPID data	18.9

Importance of resolution for ocean heat uptake



Zhang and Vallis, 2013

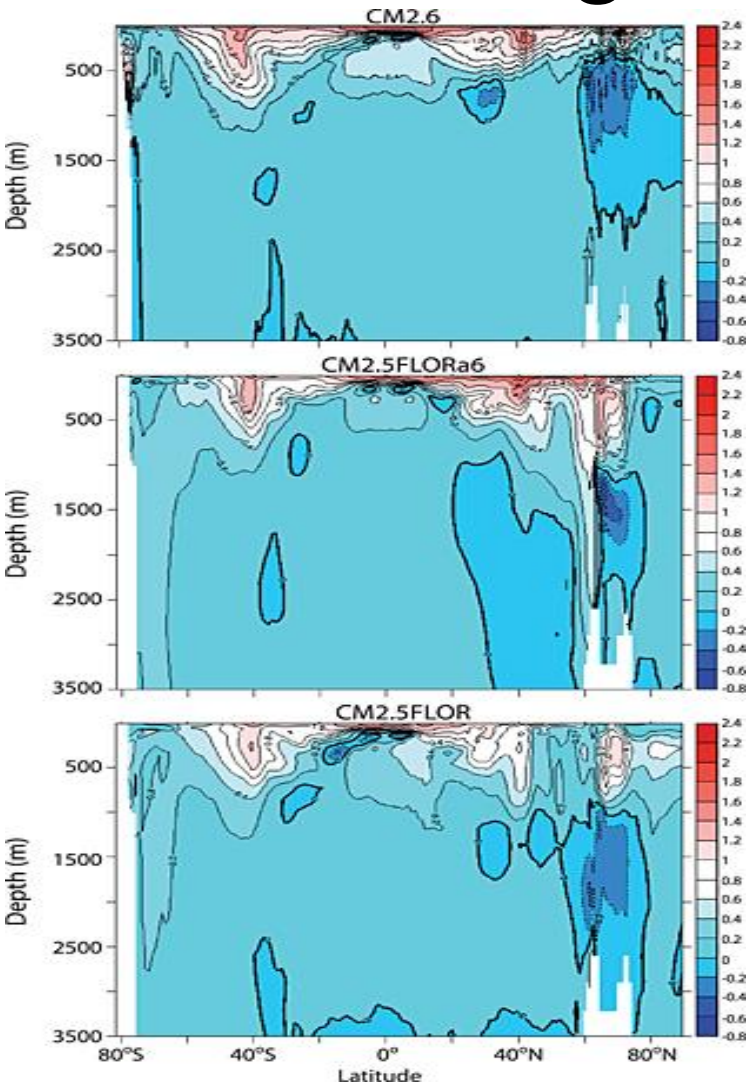


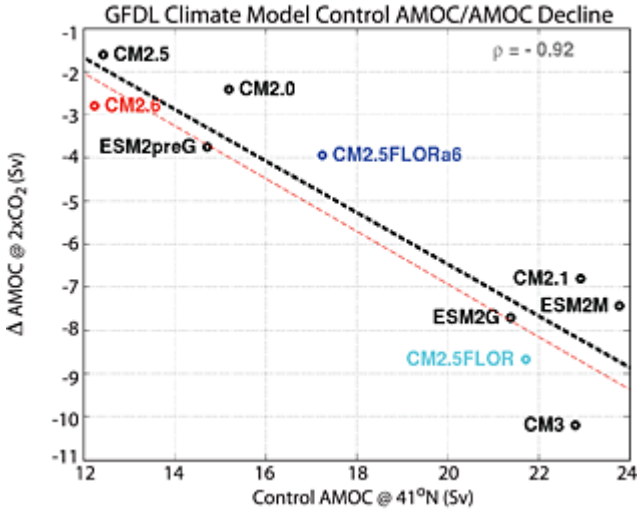
Banks and Gregory, 2006

Heat uptake increases with eddy resolving model

Linked to large-scale circulation differences which change redistribution of heat (cf Banks and Gregory, 2006)

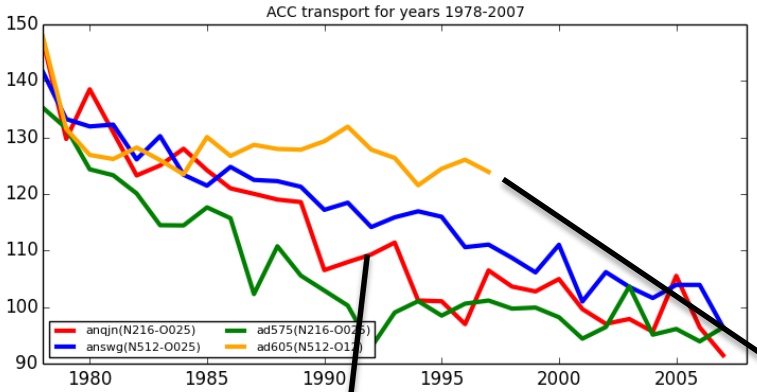
Heat uptake related to AMOC and its changes





Winton et al., 2014

Antarctic Circumpolar Current

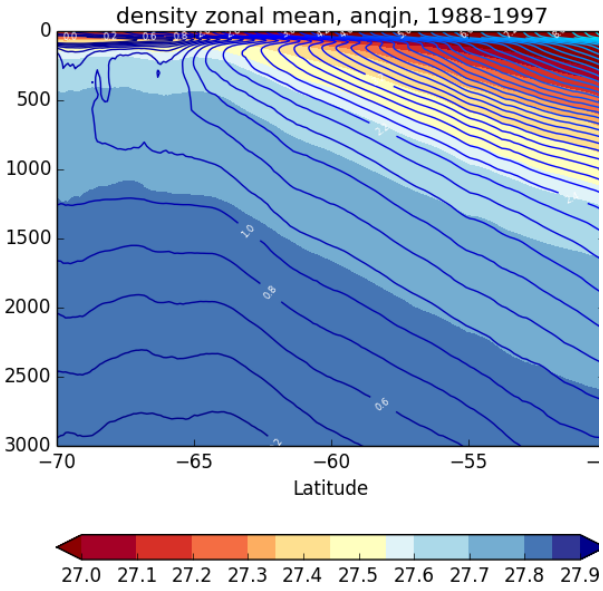


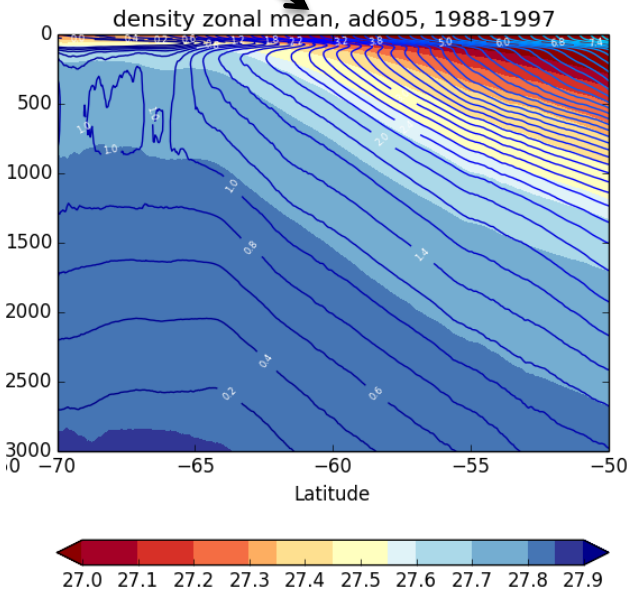
ACC more realistic

Evident in density field

Eddy-permitting

Eddy-resolving





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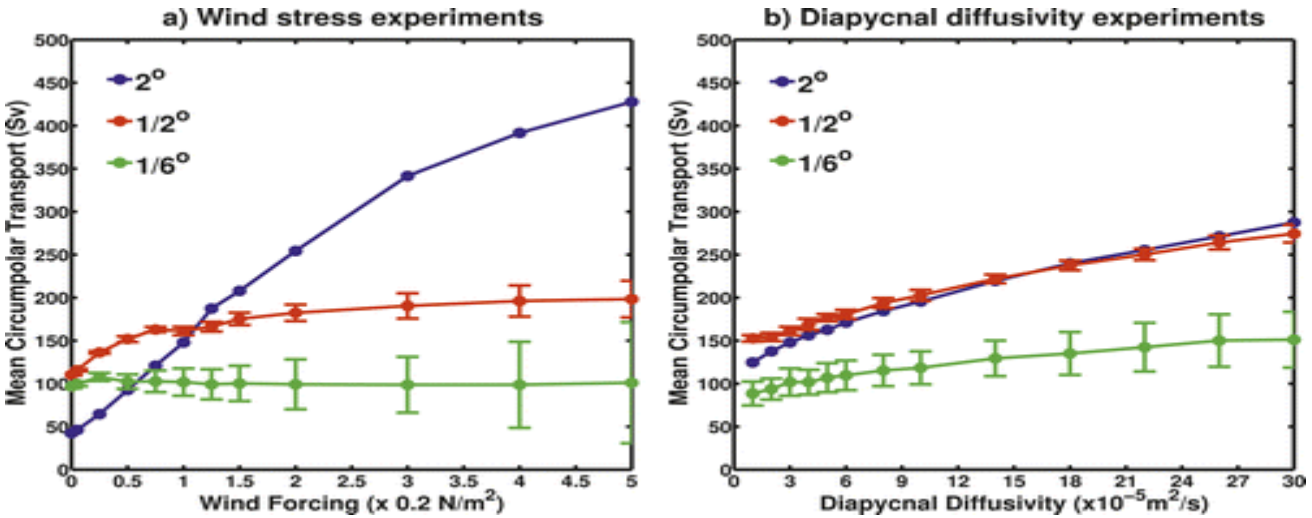
Eddy response

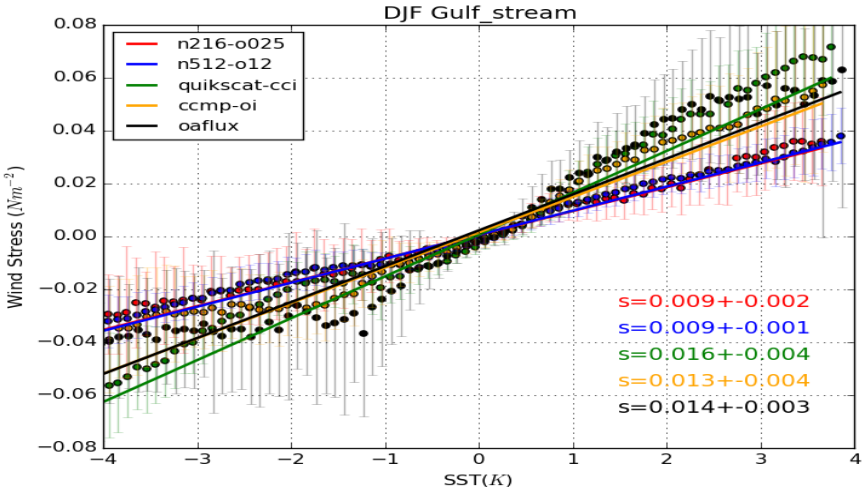


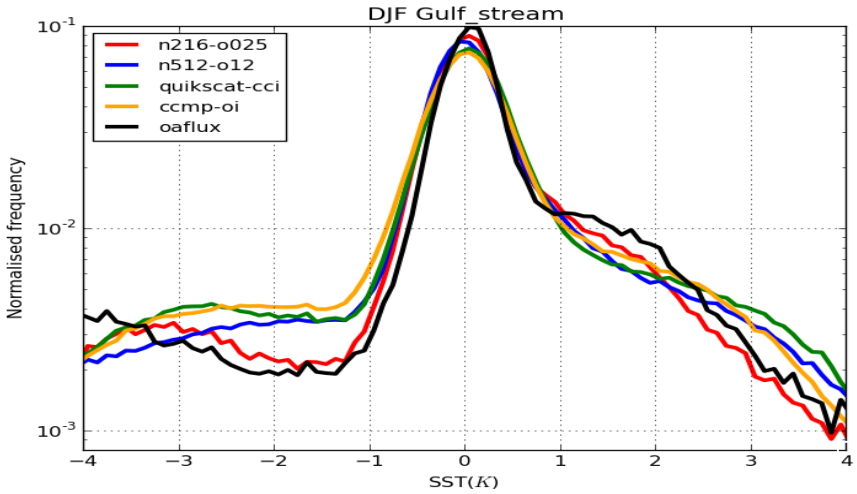
Munday et al., 2013

Eddy saturation means that the ACC doesn't spin-up in response to increased winds

Response of low resolution models could be compromised unless parameterisations can account for this

Does the atmosphere care about the ocean resolution?

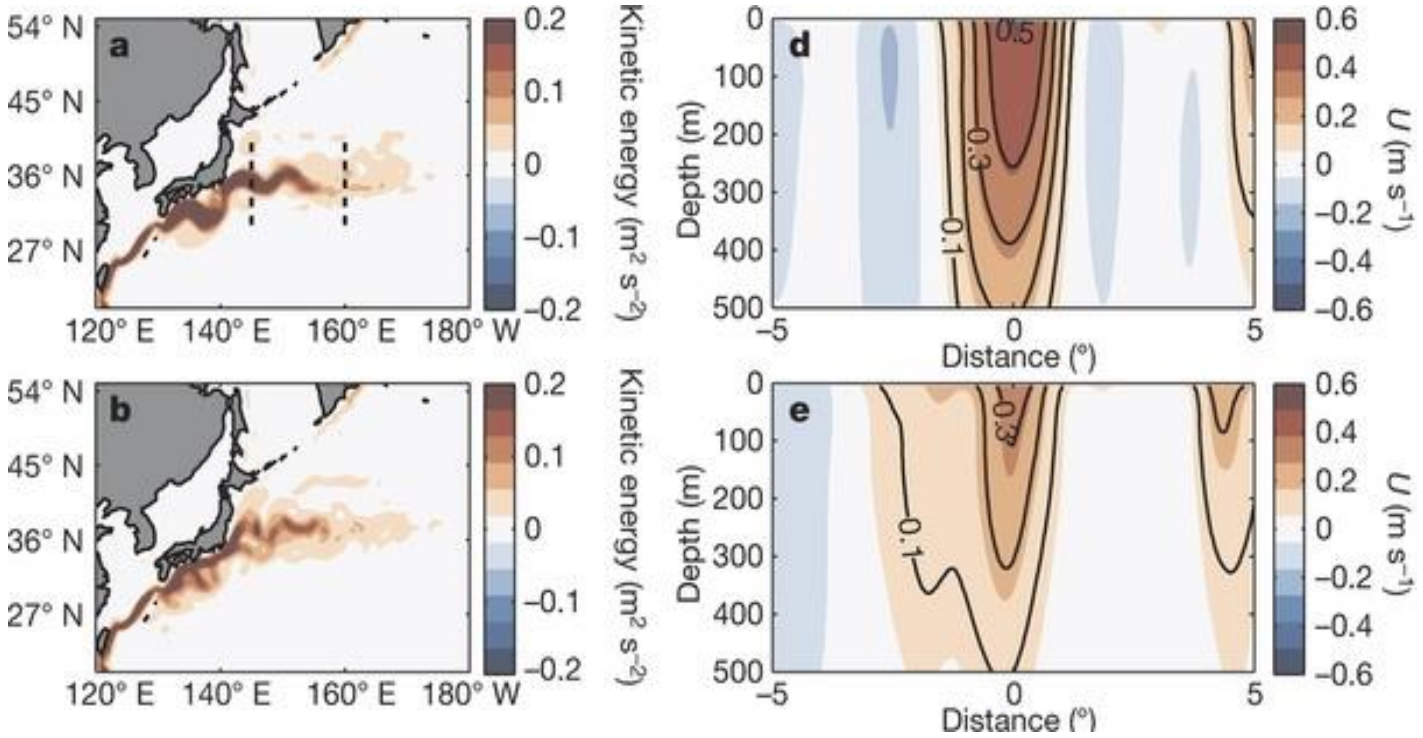




Suggestion that eddy-permitting resolution is sufficient to capture SST-wind coupling relationship

Roberts et al., submitted

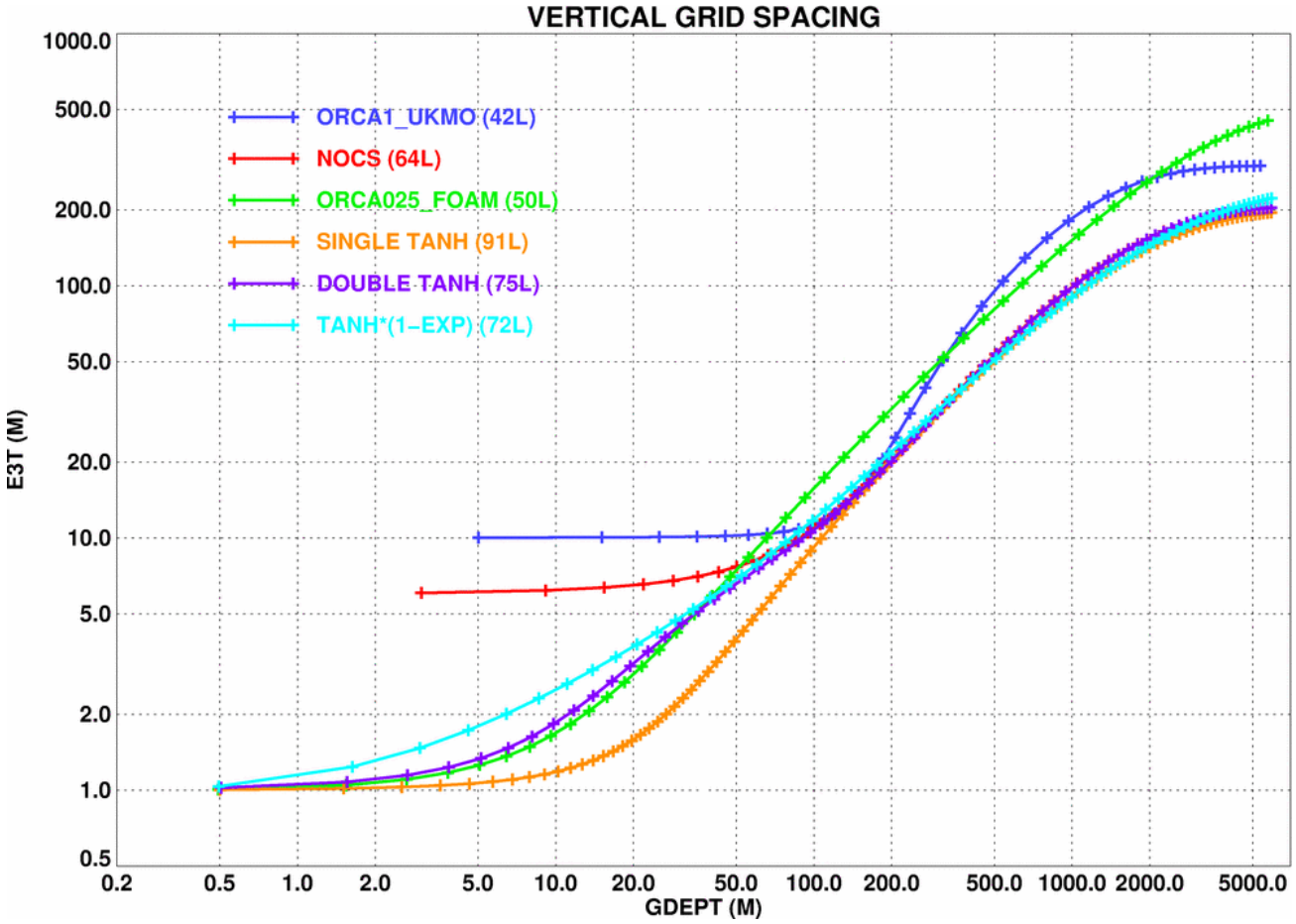
Impact of eddy-atmosphere interaction



Ma et al., 2016

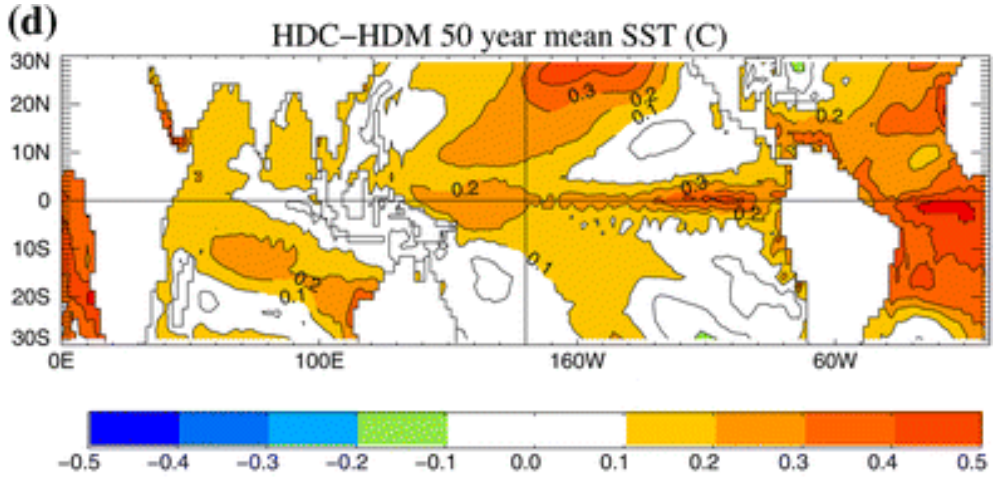
Interaction of eddies with the atmosphere impacts on the ocean circulation

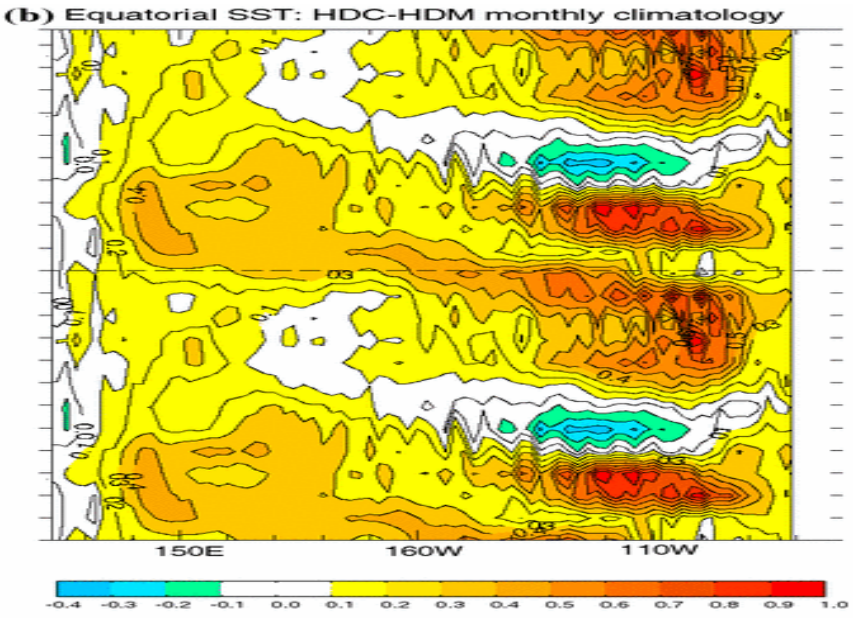
What about vertical resolution?



Ian Culverwell

Vertical resolution to resolve the diurnal cycle





Impacts include large-scale warming of SST and enhanced seasonality in Tropics

Bernie et al., 2008

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Outline

Introduction
- Resolving the Rossby radius
- Parameterisation considerations

Benefits of resolution
- Energetics
- Heat Budgets
- Tropics
- Thermohaline circulation
- Coupling

Conclusions
- Choices for your application
- Cost considerations
- Traceable model hierarchy

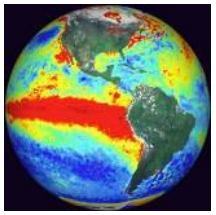
Global Physical Modelling

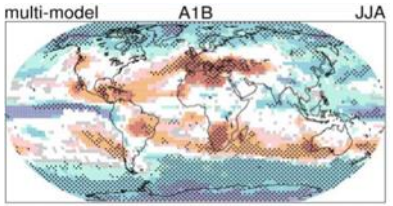
Unified Prediction across Timescales

Met Office

Hours Days Weeks Months Seasons Decades Centuries

1/12° 1/4° 1°





NWP - Atmosphere, Ocean, Waves
Deterministic MOGREPS

GloSea Decadal

Climate Change &
UKESM1

Component Models	Coupled AOIL Model
GA7 , GL7, GO6, GSI7/8	GC3.0

Met Office Unified Model™ Global Atmosphere

JULES Global Land

NEMO Global Ocean

CICE Global Sea Ice

WaveWatch III Global Waves

Thoughts on resolution choice

Short range ocean forecasting

- resolution to resolve mesoscale features

Seasonal

- sufficient ocean resolution for accurate atmospheric circulation, Equatorial regions but also mid-latitudes

Decadal

- ocean memory becomes important – need accurate circulation particularly in subpolar gyre and overflows

Climate

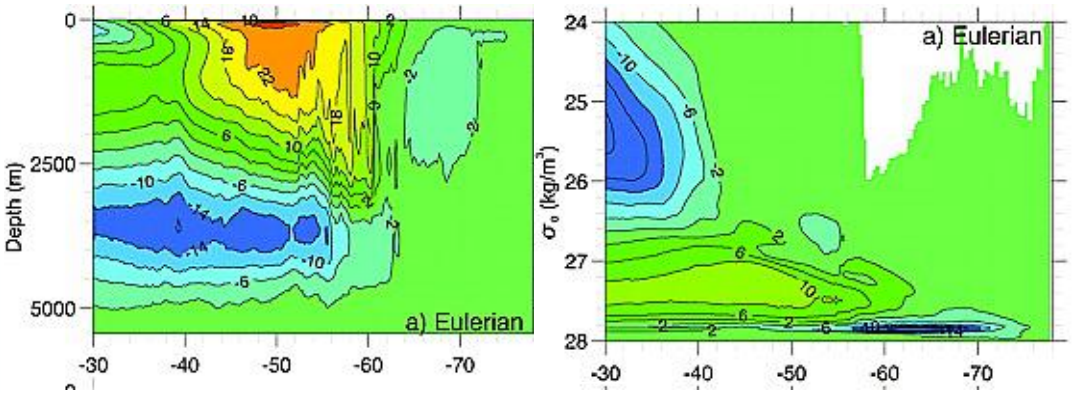
- long-term heat and freshwater budget and circulation to get accurate response (including impact of eddies)

Cost considerations

ORCA025: 1 year = 7.5 node days
<1 TB/model year

ORCA12: 1 year = 180 node days
7 TB/model year

Diagnostics need careful thought at higher resolution to diagnose budgets and overturning on density surfaces as well as track eddies

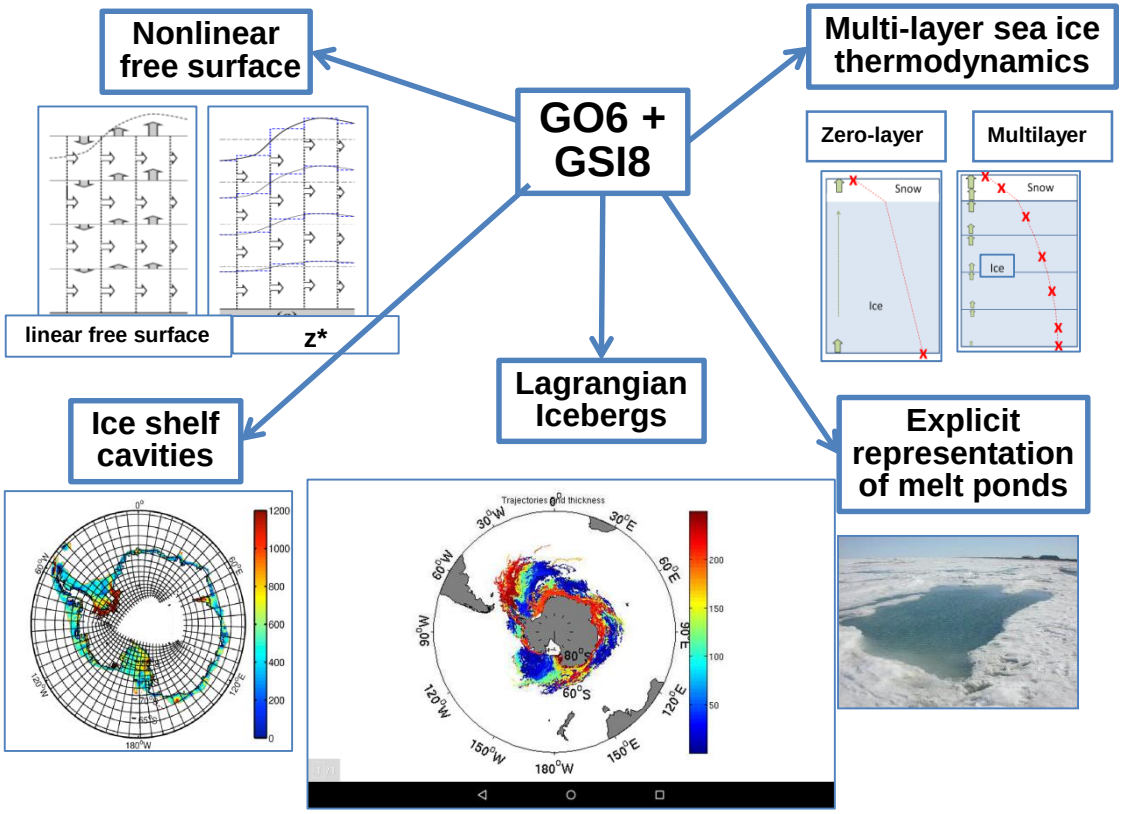


Doos et al., 2008

Traceable hierarchy at GO6

Enabling better understanding of the impacts of resolution on climate

New modelling capabilities at GO6+GSI8



ORCA12

↑

ORCA025

↓

ORCA1

Storkey et al., in prep.

Take-home messages

- Tropics and boundary currents suggest a minimum ¼° horizontal resolution
- Require sufficient vertical resolution to resolve diurnal cycle (1m near surface)
- Overflows require specific consideration (nested approach for high horizontal and vertical resolution or parameterisation)
- Benefits of eddy-resolving include eddies, fronts and topographic control. Emerging results are likely to lead to improved parameterisations or improved evidence for high resolution
- Traceable model hierarchies allow systematic assessment and enable greater understanding

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