The large-scale atmospheric response to sea ice removal in an aquaplanet AGCM

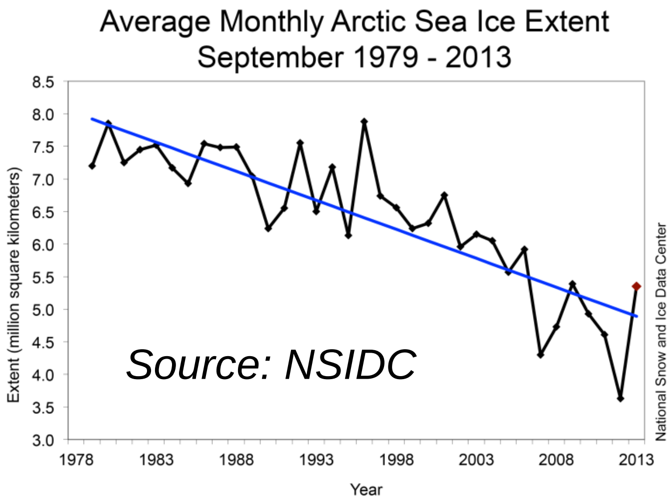
Caroline Ely

PhD student, 3rd year

Supervisors Tim Woollings, David Brayshaw and Len Shaffrey

Sea ice loss: context

- Declining trend in measures of Arctic sea ice (e.g., extent at September minimum) is observed and projected to continue



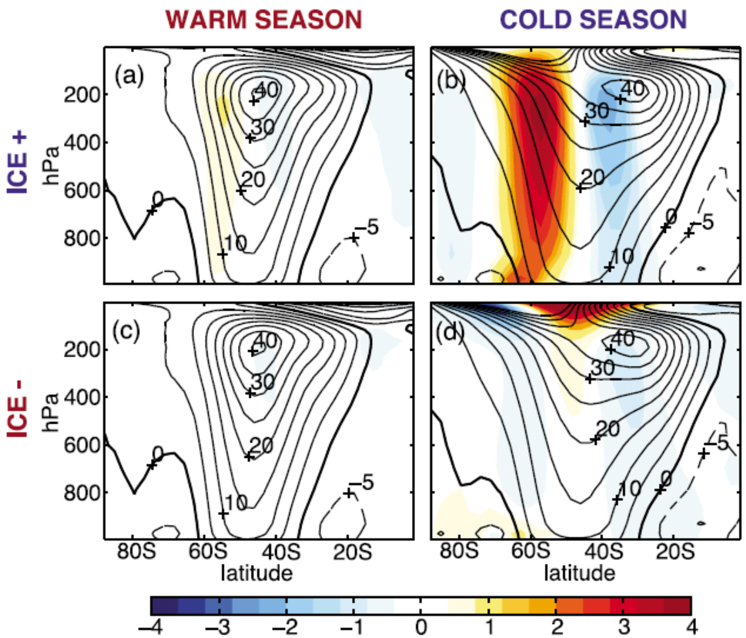
- Concentration/thickness of sea ice moderates atmosphere-ocean heat fluxes.
  - In particular, exposed ocean in summer-> ↑ ocean heat uptake-> ↑ ocean to atmosphere heat flux in autumn/winter; plays key role in Arctic Amplification (Screen and Simmonds, Nature, 2010)
  - Arctic Amplification: enhanced surface warming (c.f. global) in Arctic

Impact on midlatitude circulation

- Expect sea ice loss, and associated changes in T and gradient of T, to impact midlatitude circulation. Some studies:-
- NH: reduced sea ice cover associated with “negative-NAO-like” circulation, equatorward jet shift (winter) *(Magnusdottir et al 2002, Seierstrad and Bader 2009 etc)*
- SH: reduced sea ice cover associated with negative SAM and vice versa (*Kidston et al 2011, Bader et al 2012*)
- **Common themes; projection onto leading modes of variability; seasonal dependence; equatorward jet shift when ice removed**
- Opposes main climate signal of `poleward jet shift’ (especially SH)
- Plus; linkages to extremes in observational studies

A focus on Antarctica

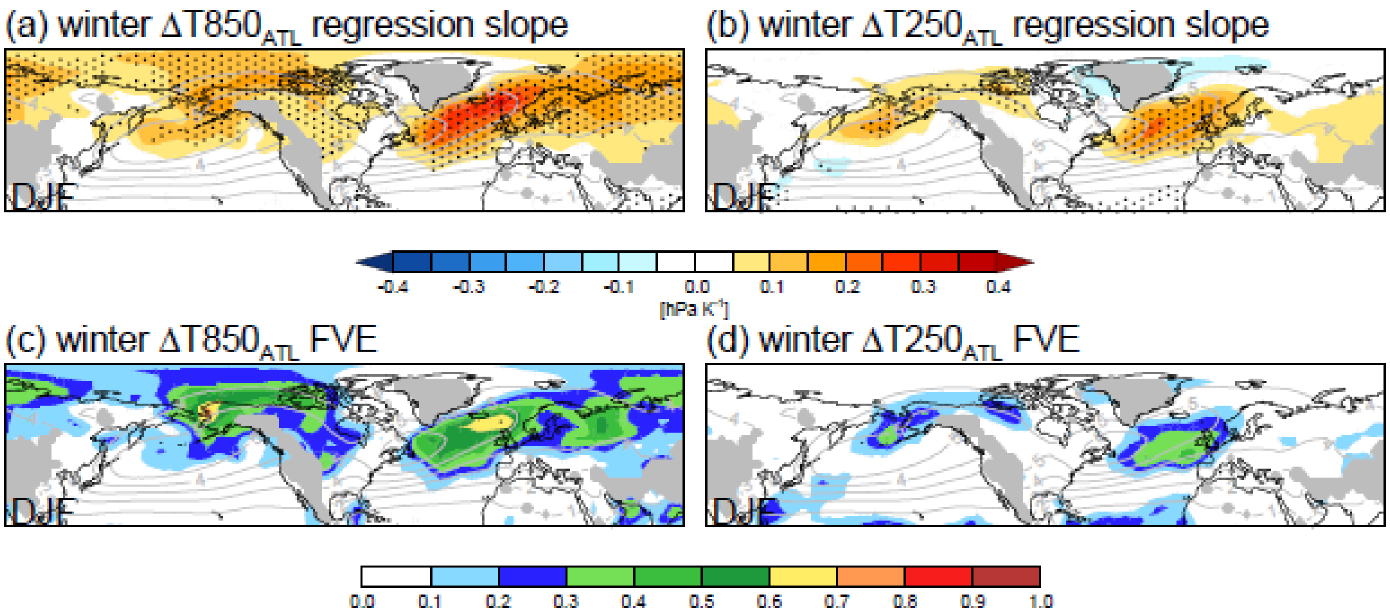
- Menendez et al1999
  - (and other earlier papers); slight equatorward shift when ice removed
- Kidston et al 2011
  - Decrease/increase cold/warm season extent by 7º. Poleward shift when ice added in cold season (ASO). Response small otherwise.
- Bader et al 2012
  - Remove sea ice as projected by model. Equatorward jet shift. Strongest heating anoms JAS, strongest projection onto SAM in September.



Kidston et al, GRL, 2011

Possible impact in models

- Differing levels of Arctic Amplification linked to differing storm track changes in CMIP5 (Harvey et al, accepted to Clim Dyn)
- Stronger AA acts to weaken storm track



Harvey et al, accepted to Climate Dynamics. Figure 8.

Key outstanding questions

1) What are driving mechanisms? Does variability/dynamic behaviour of jet stream change?
2) What role is played by interaction with mean state?

- Is atmospheric response to a given forcing moderated by original atmospheric state (e.g. seasonality; model bias in atmospheric state)
- May arise because sea ice anomaly does not affect baroclinic zone (region of eddy activity) such that eddy behaviour is unchanged (Kidston et al 2011, and many SST studies)

Therefore: simple modelling framework, to probe understanding of 1) and give us control over 2)

Framework- Aquaplanet

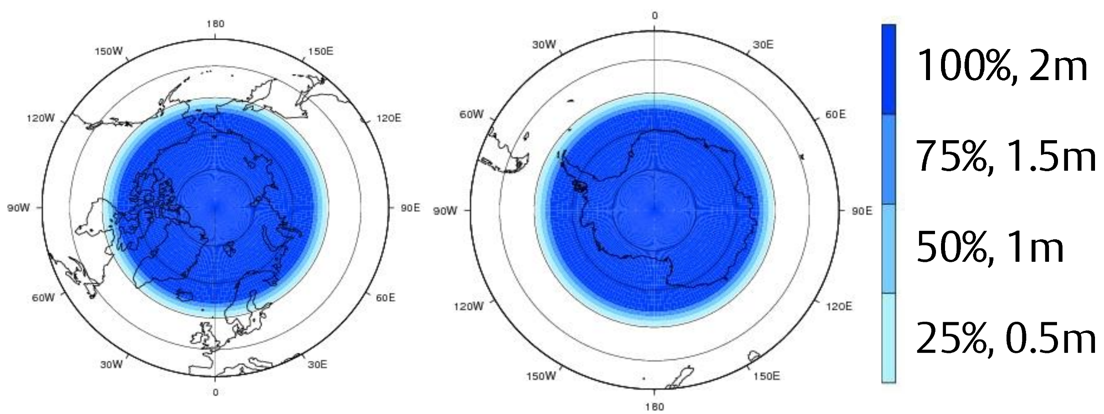
- Atmosphere only (AGCM)
  - HadGAM6.1 N96L38 resolution (1.875^{o}x1.25^{o} in horizontal)
- Axisymmetric- no land, zonally symmetric prescribed SSTs
  - Symmetric hemispheres, perpetual equinox insolation- **no seasonal cycle**
  - 5yr runs; discarding yr1 and averaging hemispheres = 8yrs data
  - Sea ice depth/concentration prescribed

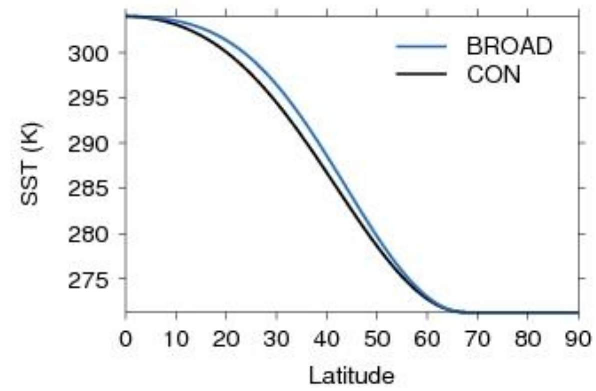
Investigate the atmospheric response to imposed (SST and) sea ice

Forcings- SST and initial sea ice profiles

	NO ICE	ICE 80-90º	ICE 70-90º	ICE 60-90º
CON SST	CONNOICE	CONICE80	CONICE70	CONICE60
BROAD SST	BROADNOICE	BROADICE80	BROADICE70	BROADICE60

Imposed sea ice (ICE60 case- continents for scale only) and SST:





Mean u and T response; CON SST

- Effect of ADDING ICE (so reverse for ‘climate change signal’)

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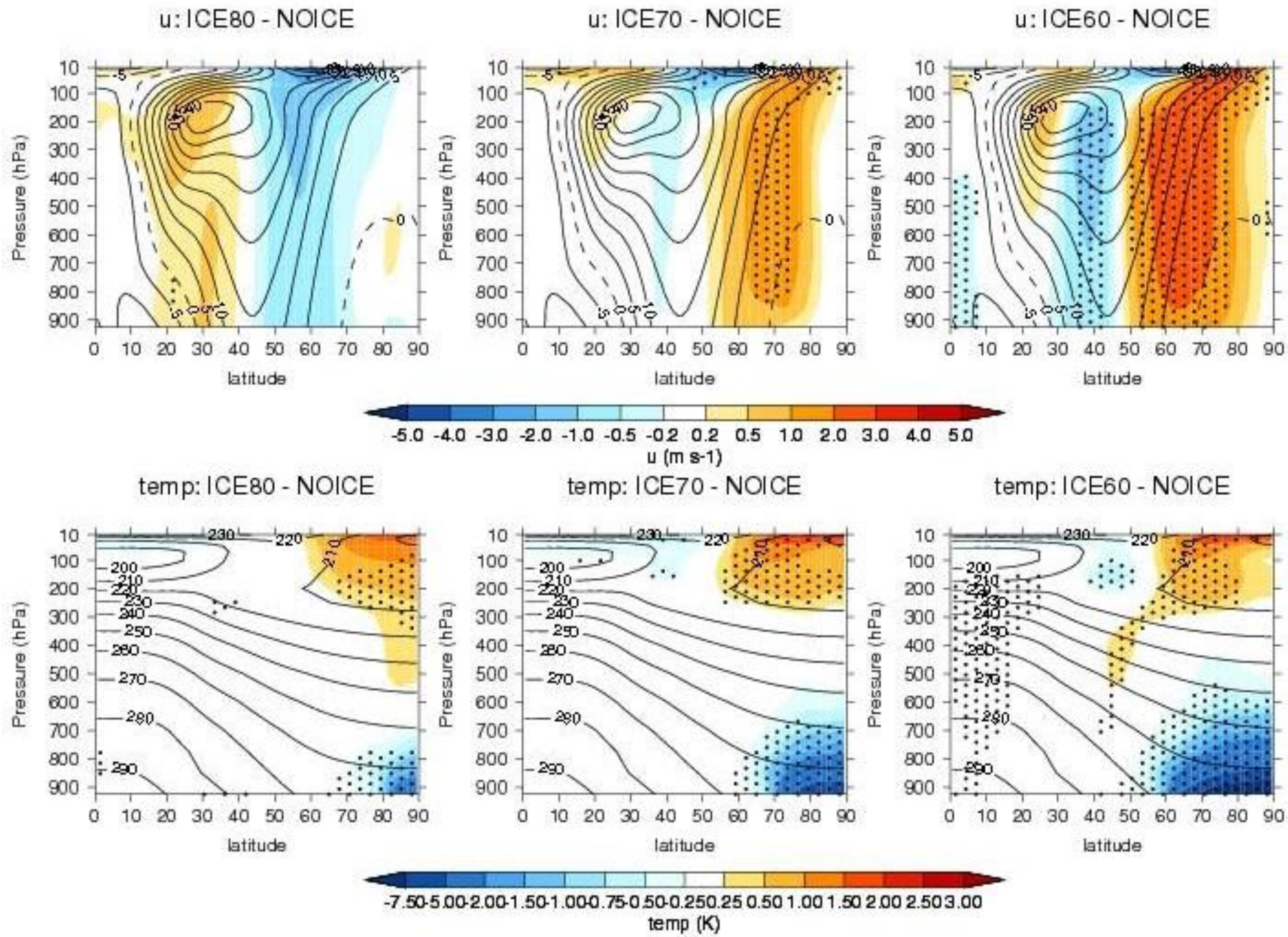
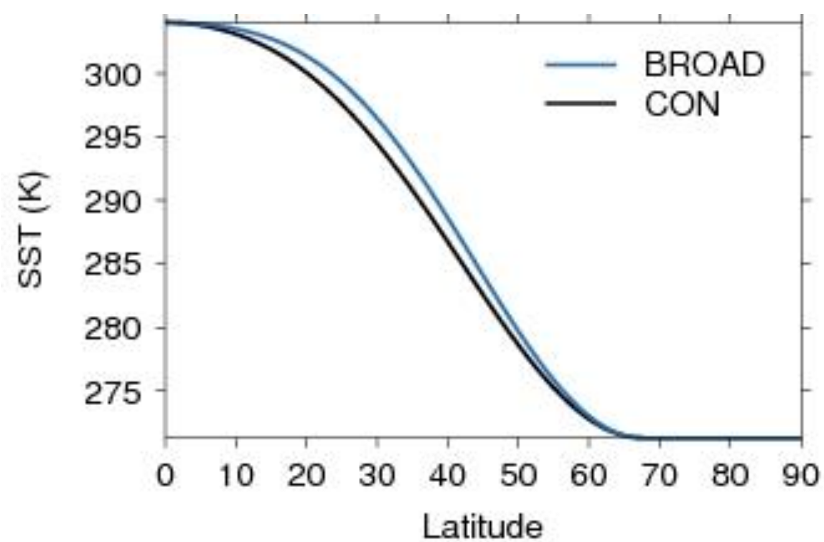


Response discussion; CON SST

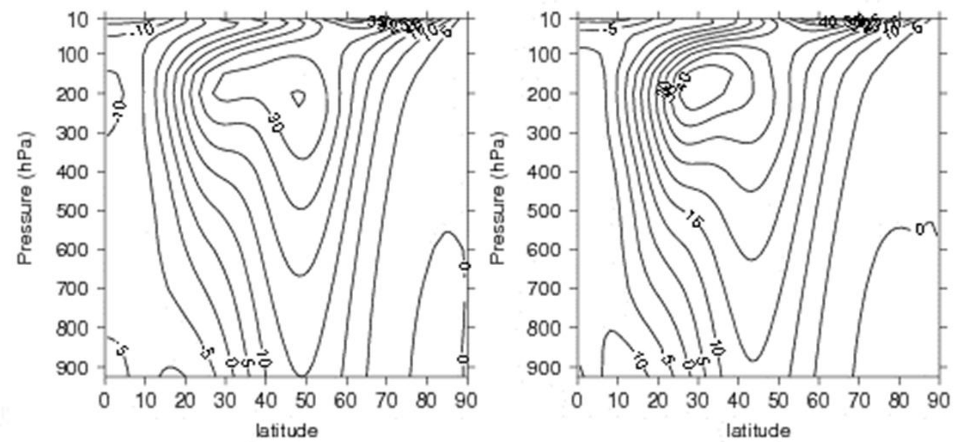
- Temperature; strong cooling below 500hPa, heating aloft
  - Mostly local to forcing but extends 10º equatorward
  - 1.5m temperature response magnitude >20K at pole
- Zonal wind: poleward jet shift / enhancement on poleward flank when ice added, plus remote response (enhanced subtropical jet)- But ICE80 case in opposite sense.
- Enhanced momentum flux into jet due to eddy activity?

Broad SST control state

SST profiles



Zonal mean zonal wind;
BROAD (left), CON (right)



Broad SST profile different in tropics; and region of strong baroclinicity extends further polewards

-> different jet structure

Responses: Broad SST

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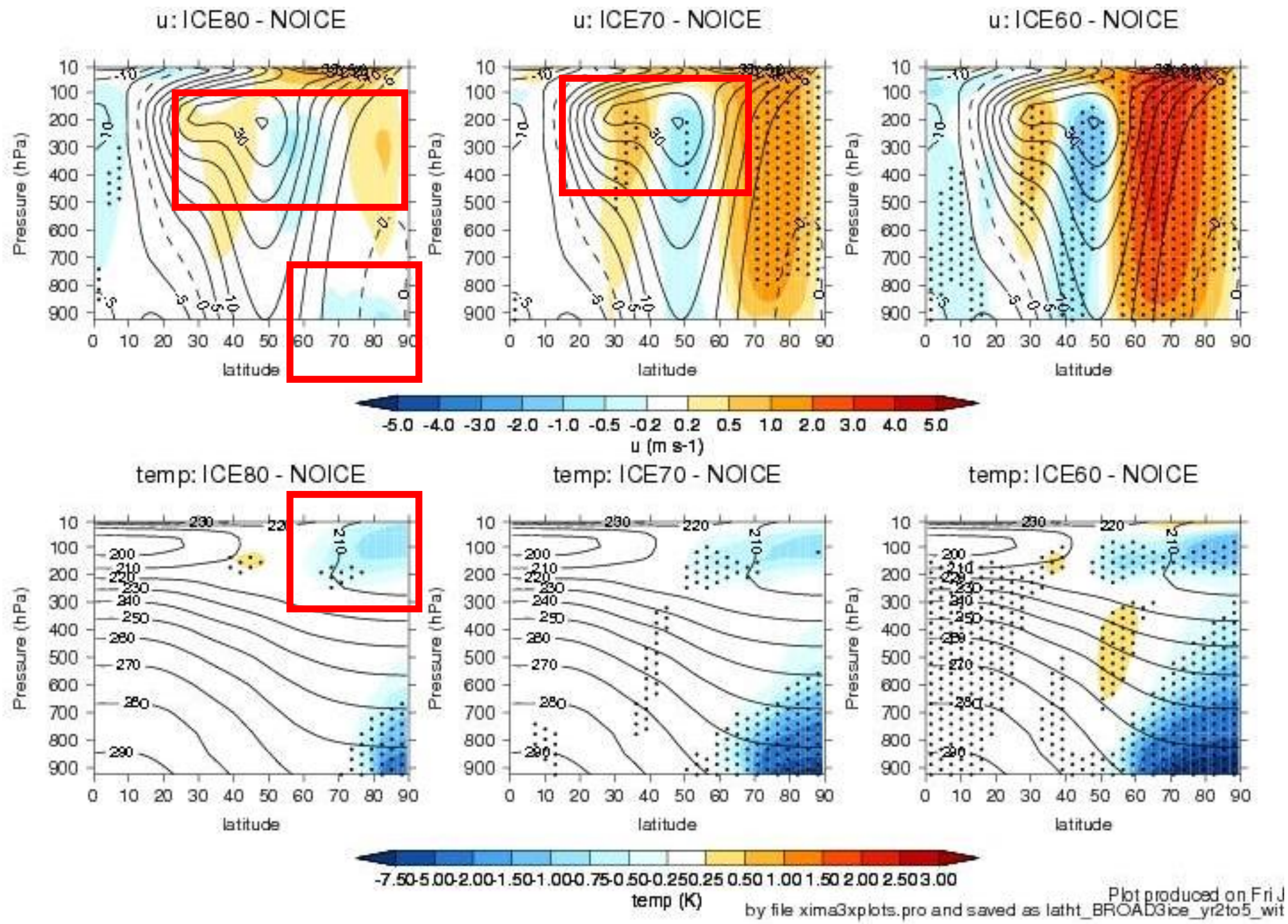
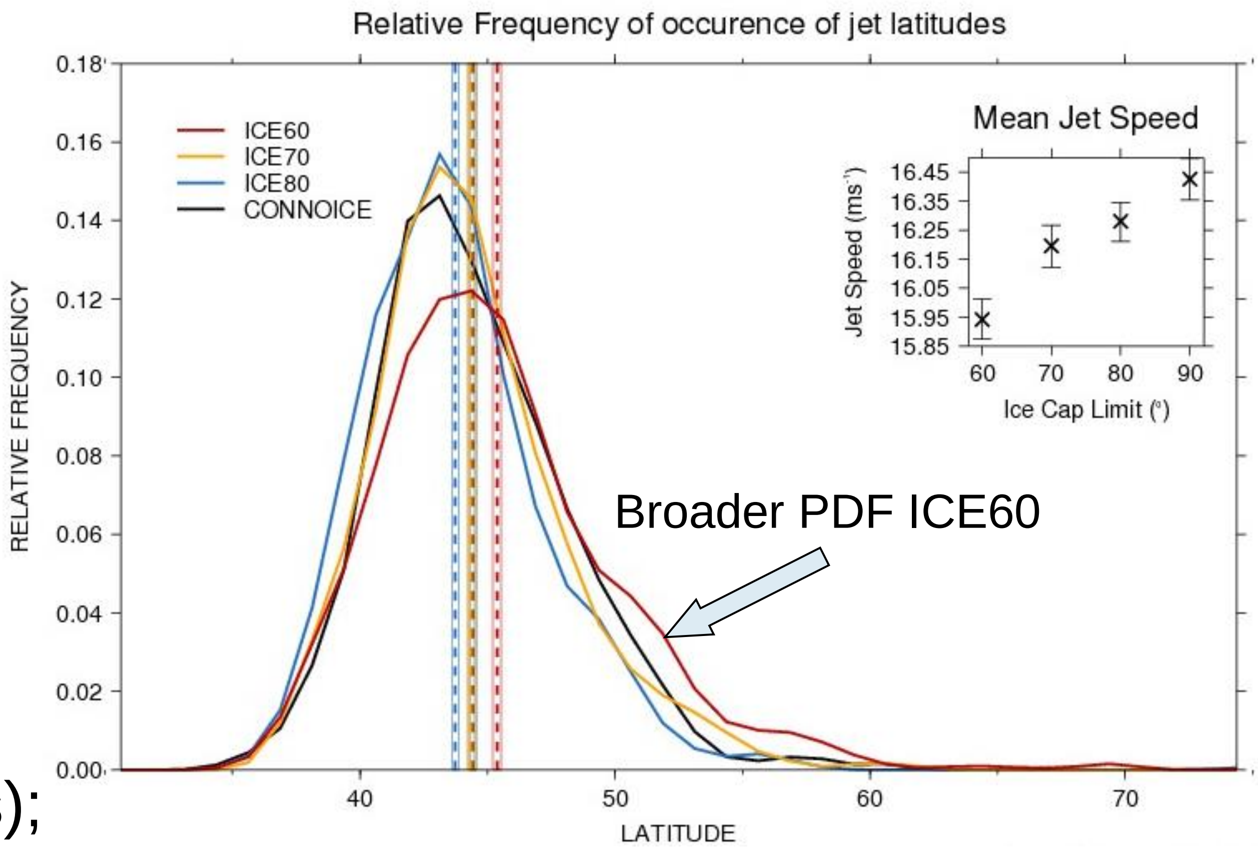


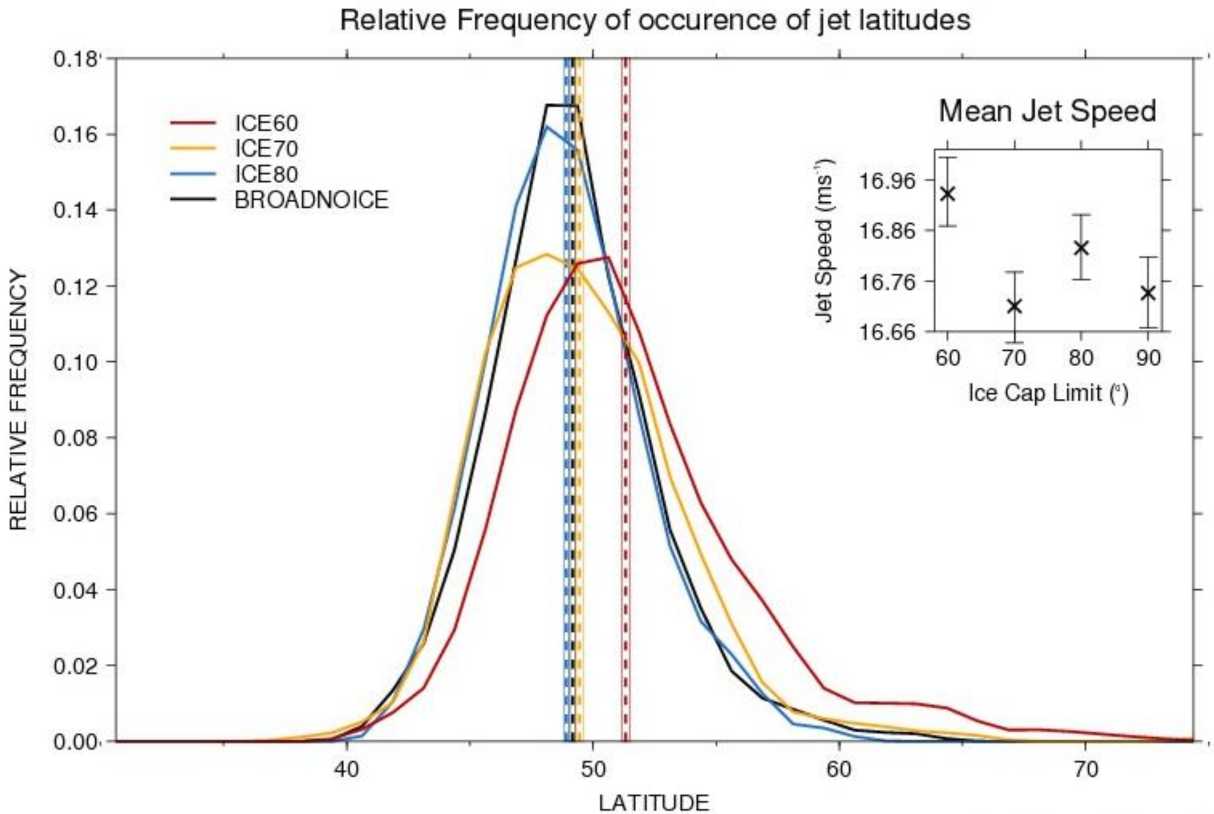
Another perspective: JLI (CON SST)

- Jet Latitude Index (Woollings et al 2010)
- VALUE and LATITUDE of max zonal mean wind each day
- Latitude PDF and mean (vertical lines); and mean jet speed



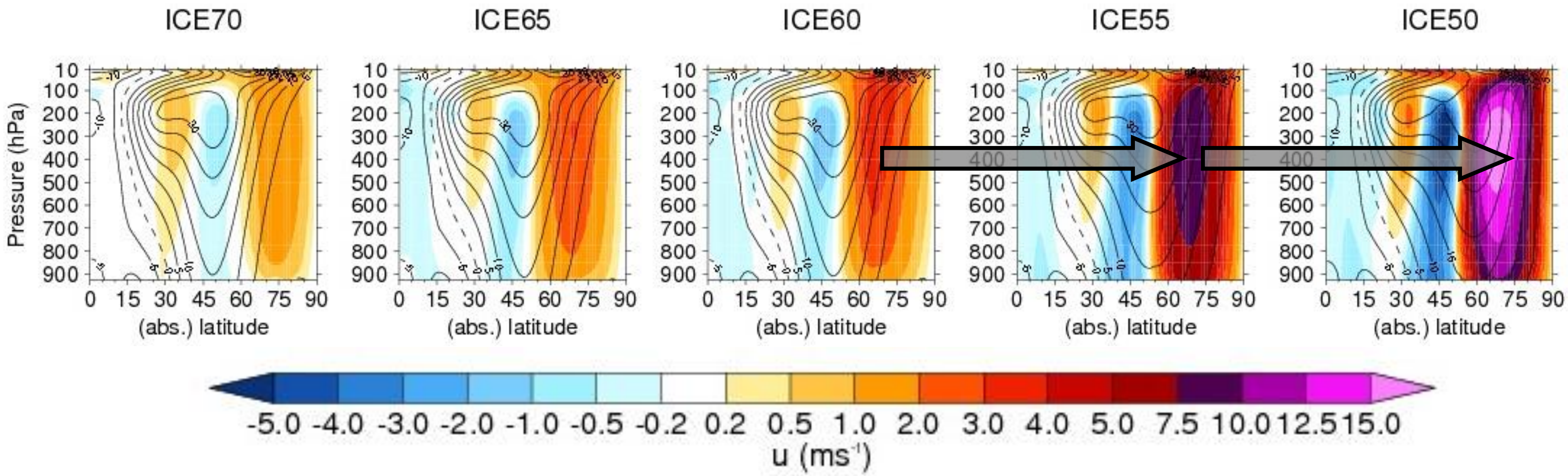
BROAD SST

- Latitude: ‘broadened distribution’ in ICE70 case too
- But notable change of mean only in ICE60
- Jet speed different; ICE70 due to reduction in jet core



BROAD SST focus

- More experiments with more extended ice

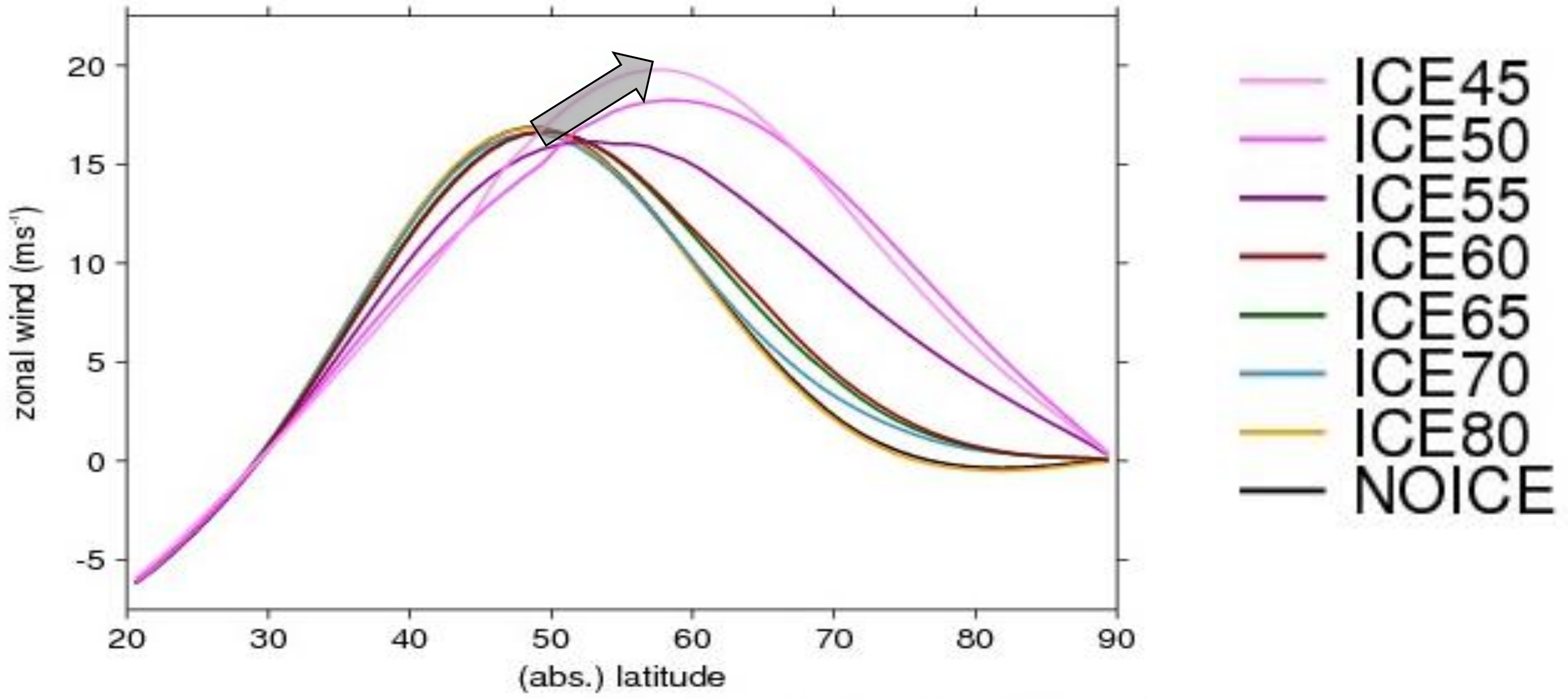


- Three (related) questions:

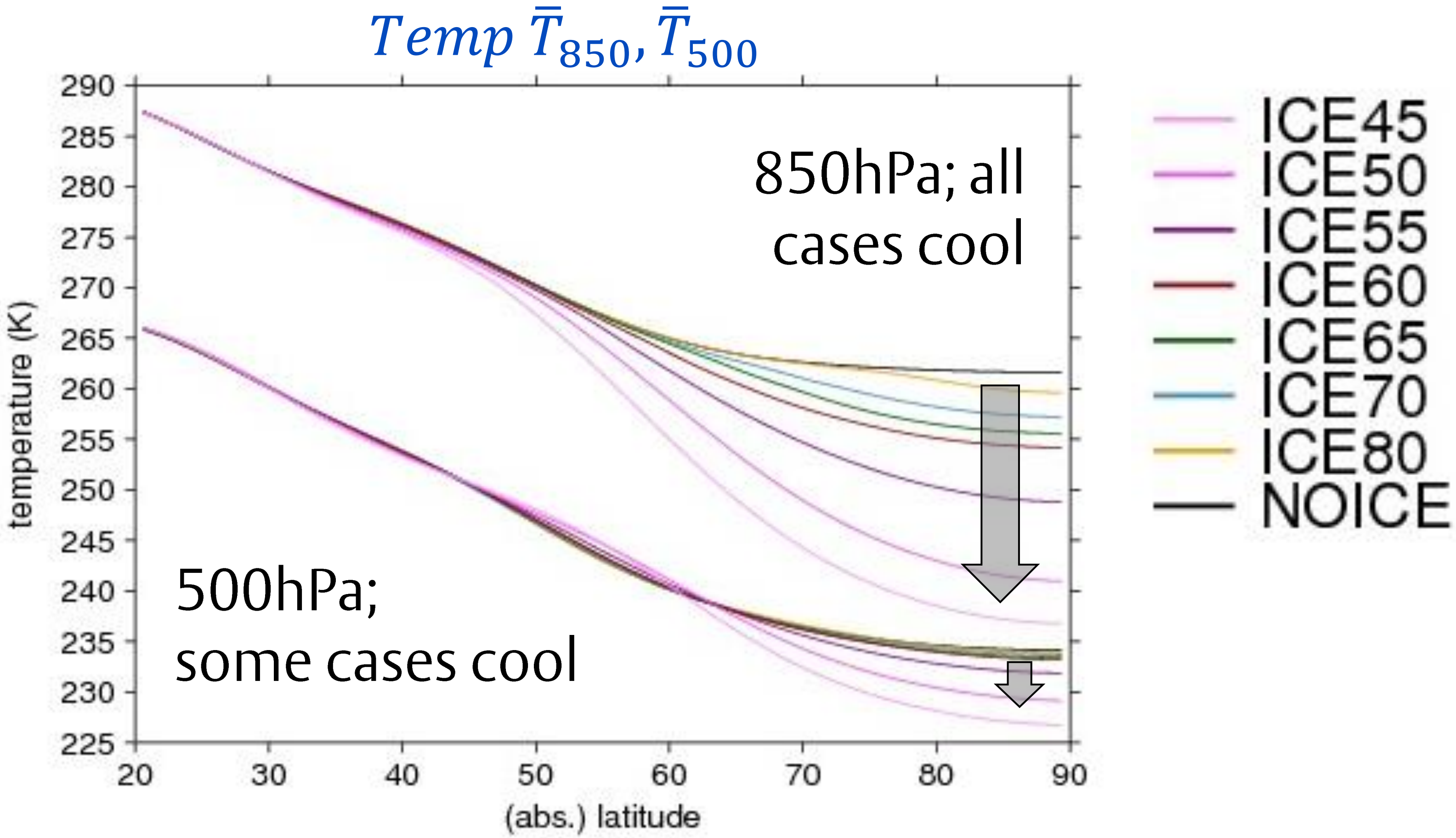
What triggers stronger response? What role are dynamics (wave-mean flow interaction) playing? Do different experiments have similar variability; can this inform understanding of the mean?

Jet overview

$EDJ\ \bar{u}_{925-700}$

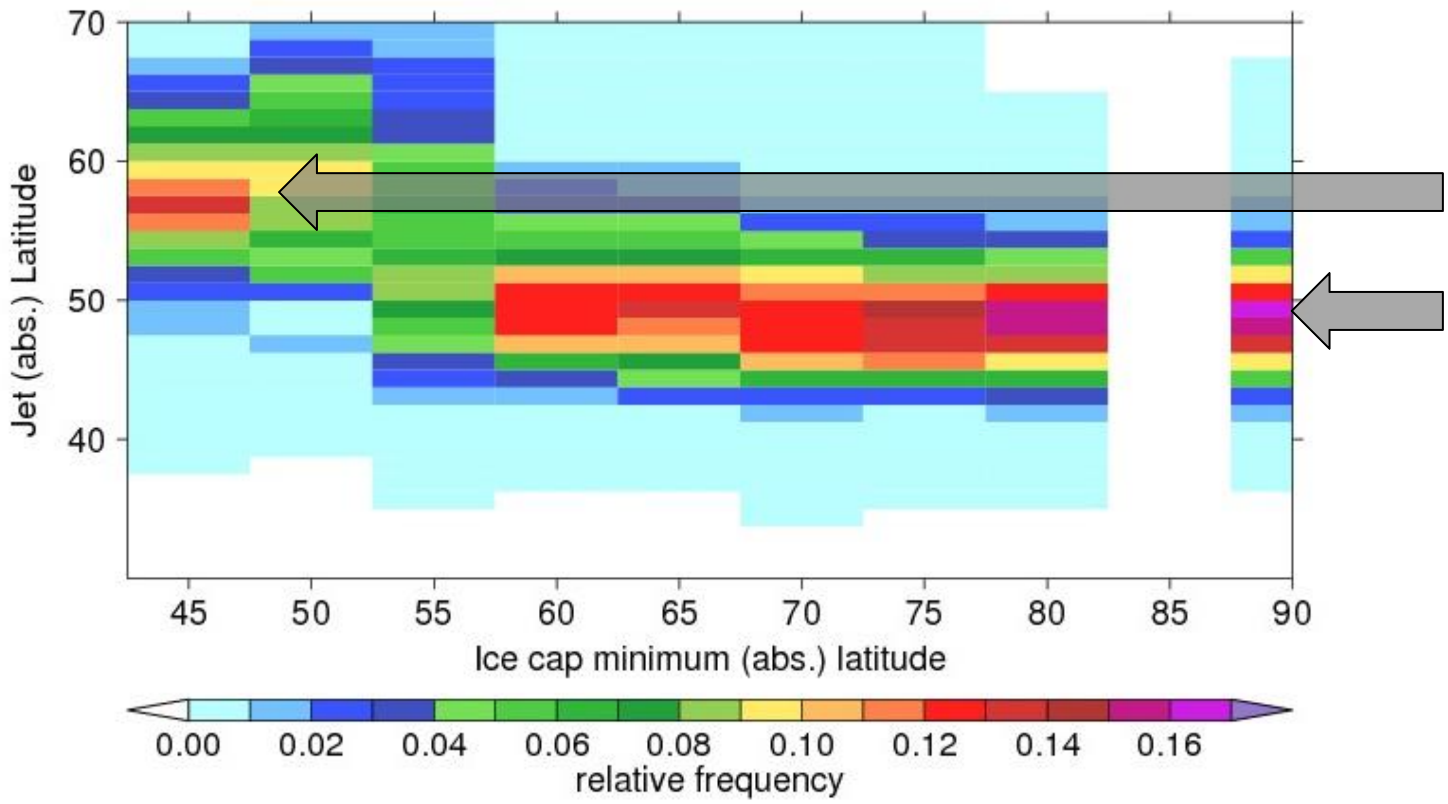


1) Temperature response (BROAD SST)



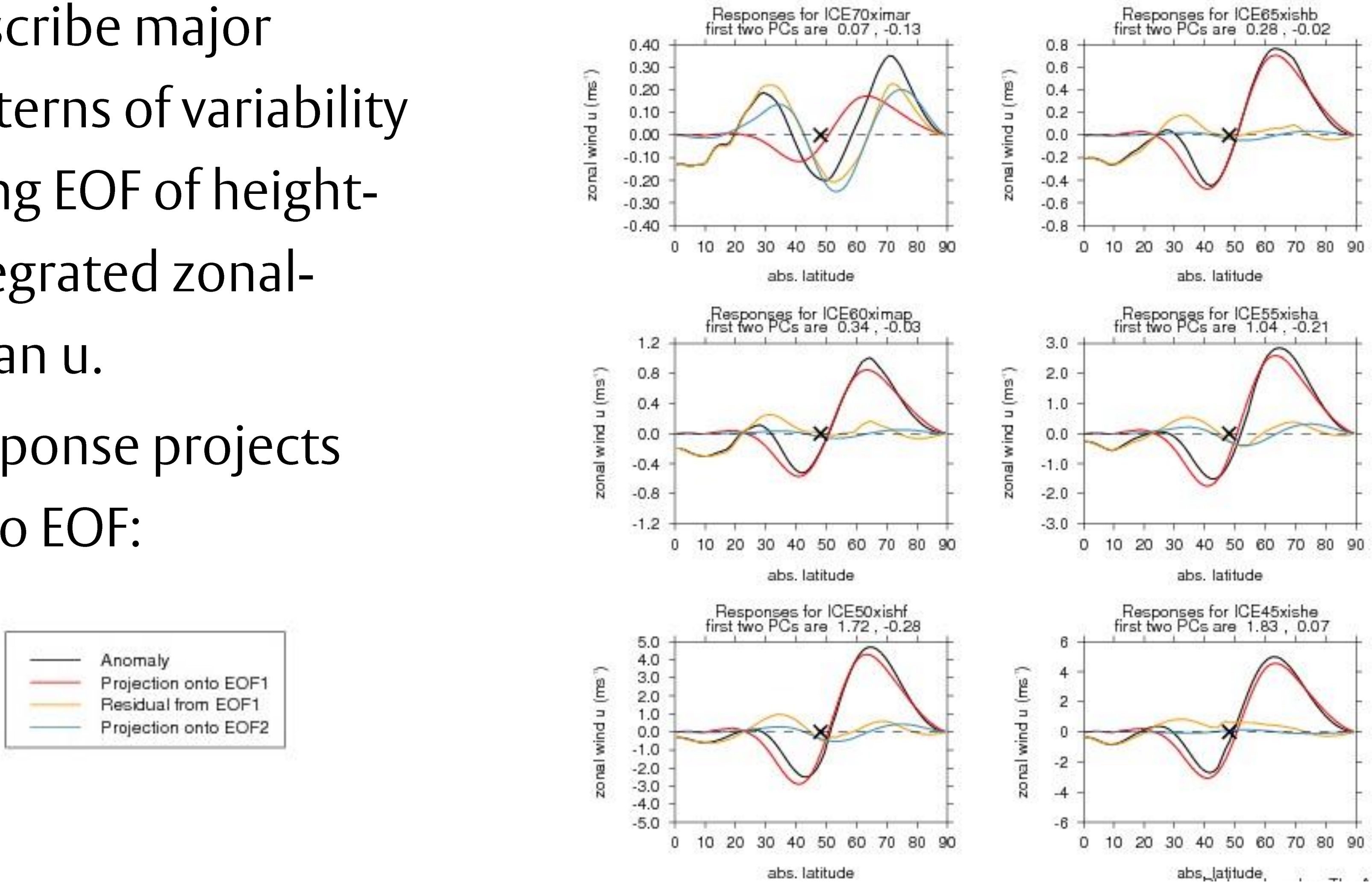
2) Variability: JLI

PDF of jet (u925-700) latitude, all expts



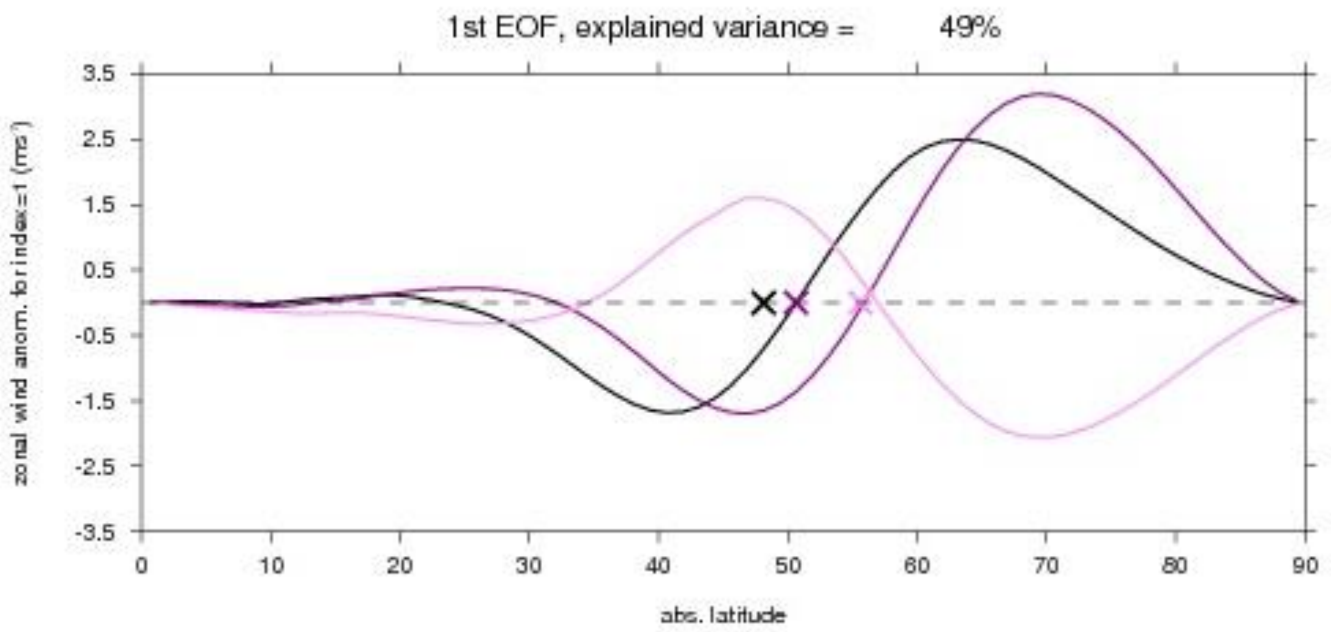
Variability: EOFs

- Describe major patterns of variability using EOF of height-integrated zonal-mean u.
- Response projects onto EOF:



EOFs 2

- Also want to understand variability within each experiment



Dynamics?

- …work in progress!
- Some thoughts:
  - Changed jet structure (ie strengthened poleward flank- decreased du/dz on flank) could change wave breaking (critical line theory)
  - Wave-mean flow interaction; this can affect feedbacks onto strength of jet
  - Baroclinicity at ice edge (or remotely) affecting eddy growth.

Conclusions and hypotheses

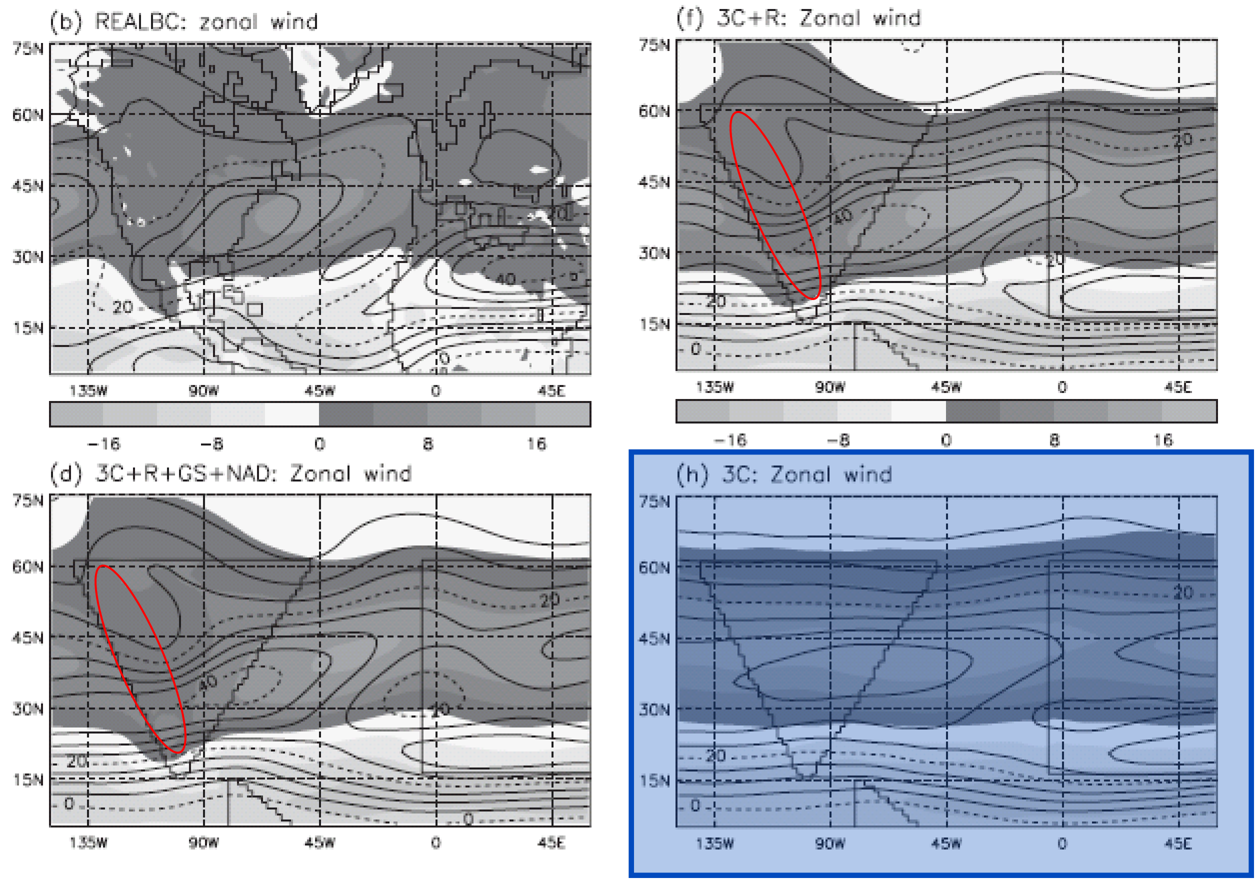
- Simplified models to probe mechanisms and understand decoupled components
- In general, jet response as expected; poleward shift under ice addition. But speed argument may not be obvious
- Evidence (from BROAD vs CON, ICE70 case) of sensitivity to mean state

- Need to further investigate role of eddies
- Also, further perturb basic state…

Future Work

Add asymmetries (land masses and orography);

- modifies zonal wind
- creates characteristic ‘tilt’ in N. Atlantic jet



Zonal wind at 850hPa (shading) and 250hPa (contours) under various asymmetries. Amended from Brayshaw et al 2011, Figure 3.