THE STRUCTURE OF EXTRA-TROPICAL CYCLONES IN A WARMER CLIMATE

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Thanks to Glenn Carver, Filip Váňa & Gabi Szépszó (ECMWF)
Helen Dacre and Kevin Hodges (University of Reading)

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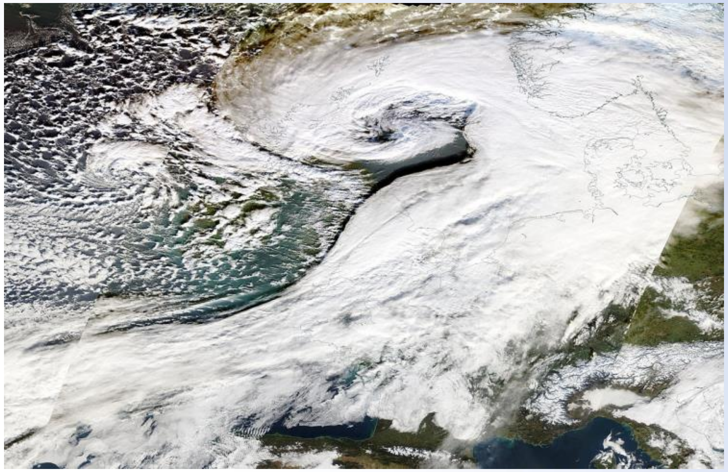
Impacts of extra-tropical cyclones

- Heavy precipitation and strong winds are associated with extra-tropical cyclones

- Will the location of these extremes change in the future?
  - Geographically
  - Relative to the cyclone centre

- Will the size of area affected by such extremes increase or decrease?



Aim

How does the structure of extreme (and average) extra-tropical cyclones respond to an increase in temperature?

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Idealised Approach

Given the

- *uncertainty* in climate models projections
- the *difficulty in interpreting results* from sensitivity experiments in coupled models

– Idealised aqua-planet simulations with fixed SSTs

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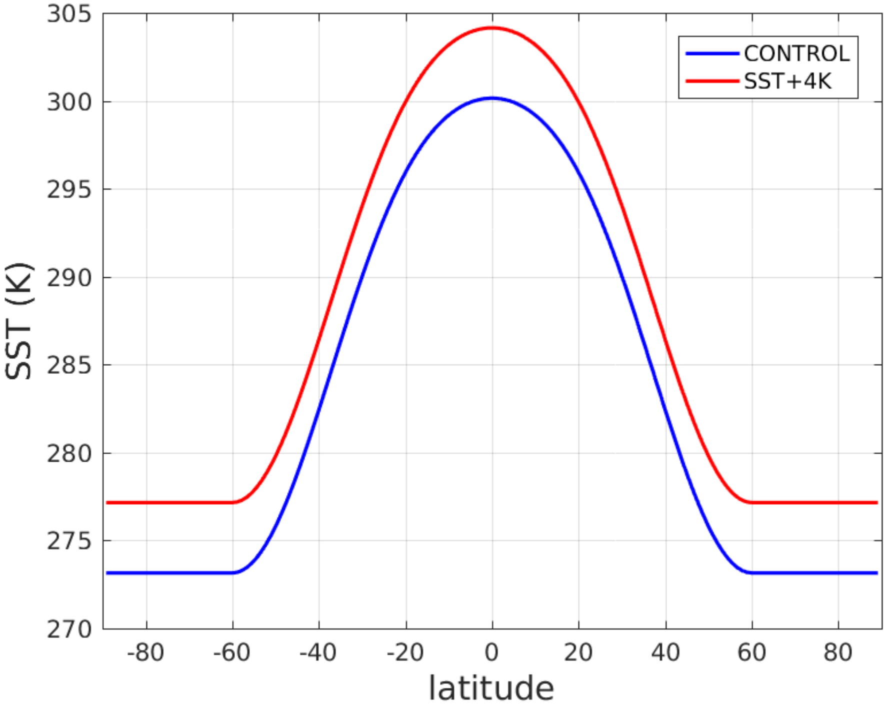
Aqua-Planet experiments

- Two 11-year simulations with OpenIFS
- Control (Qobs)
- Warm SSTs by 4K uniformly
- SSTs are fixed
- T159 (1.125°) L62
- No seasonal cycle – equinox



- Domain mean 2m-T = 13.5C

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Identify Extra-Tropical Cyclones

- Objective feature tracking algorithm TRACK (Hodges, 1995; Hodges 1999)
- Find localized maximums in ***850-hPa relative vorticity*** truncated to T42
- Track all cyclones in the Northern Hemisphere
- Exclude cyclones which do not
  - last at least 2 days
  - travel 1000 km
  - have at least on point north of 20N

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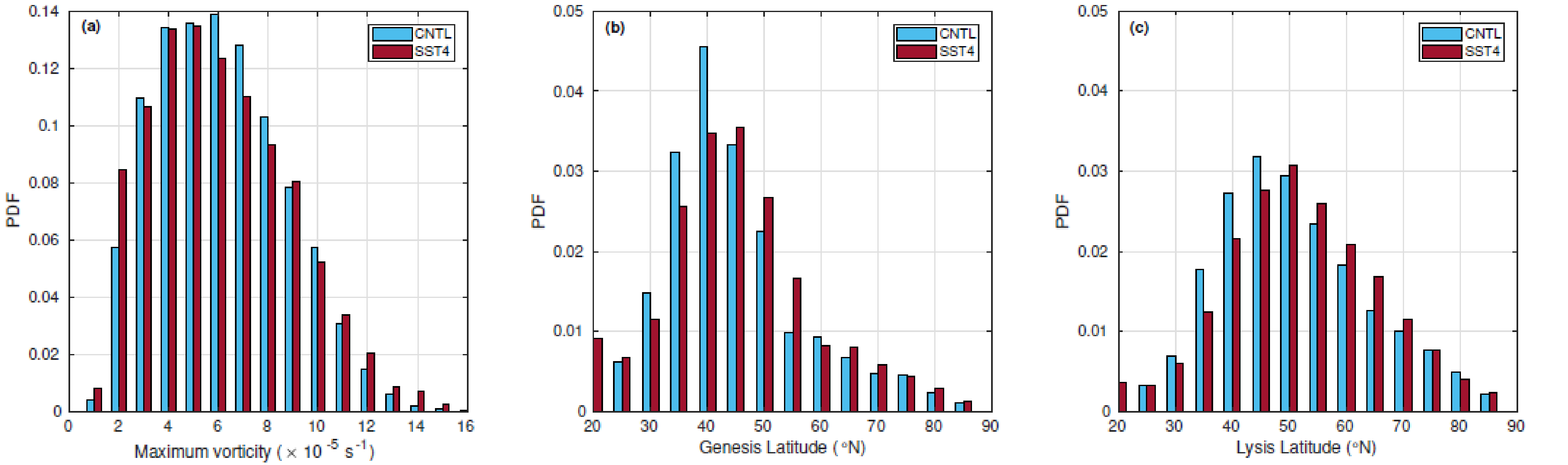
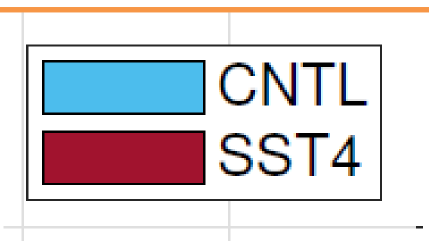
Change to bulk cyclone statistics

Maximum vorticity | Genesis Latitude | Lysis Latitude



- Mean and Median intensity of ETCs do not change
- Standard deviation of maximum vorticity increases
- Number of ETCs decreases by 3.3%
- Median Genesis and Lysis latitudes move polewards by 2.0 and 1.9 degrees



Catto et al (2010). J. Climate

Create Cyclone Composites

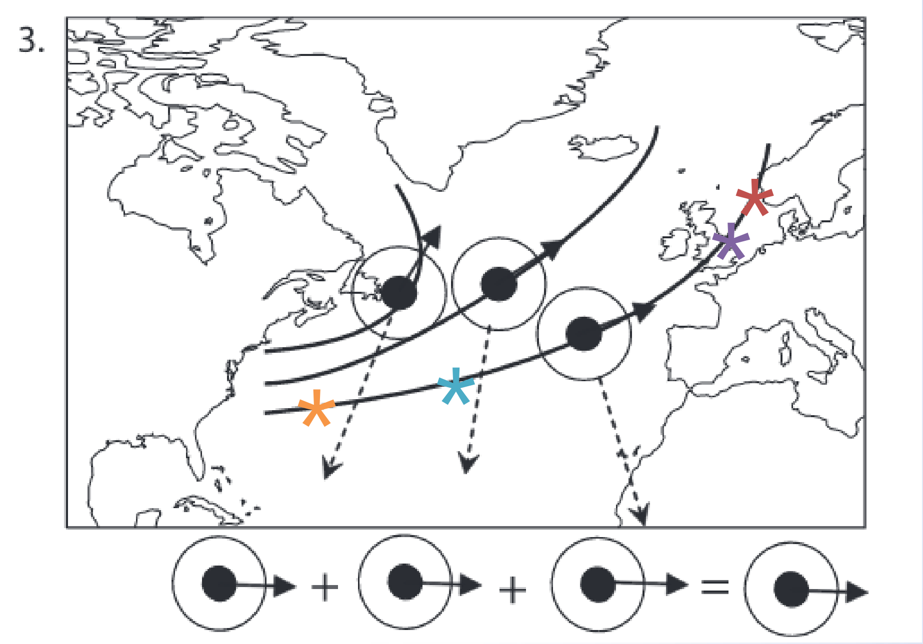
Step 1: Find the strongest 200 storms

Step 2: Find the position of maximum intensity along the track (t=0) and other offset times (t=-48 hr, -24 hr, +24hr etc.).

Step 3: Interpolate variables from model output grid to spherical grid centred on each cyclone centre at each offset time

Step 4: Rotate all cyclones so that they are travelling in the same direction

Step 5: Average all 200 cyclones separately for each offset time to obtain a composite mean.



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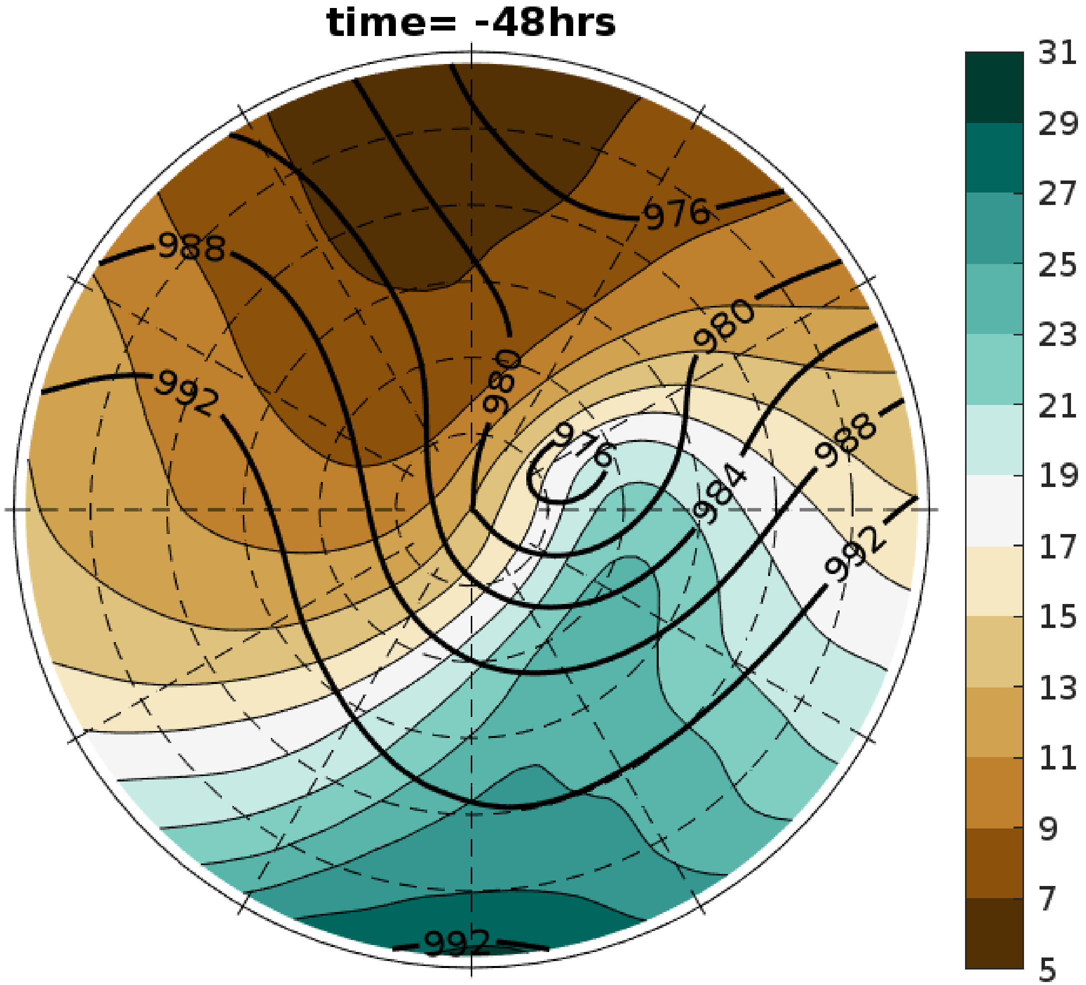
Composite cyclone t=-48 hrs

Shading show total column water vapour

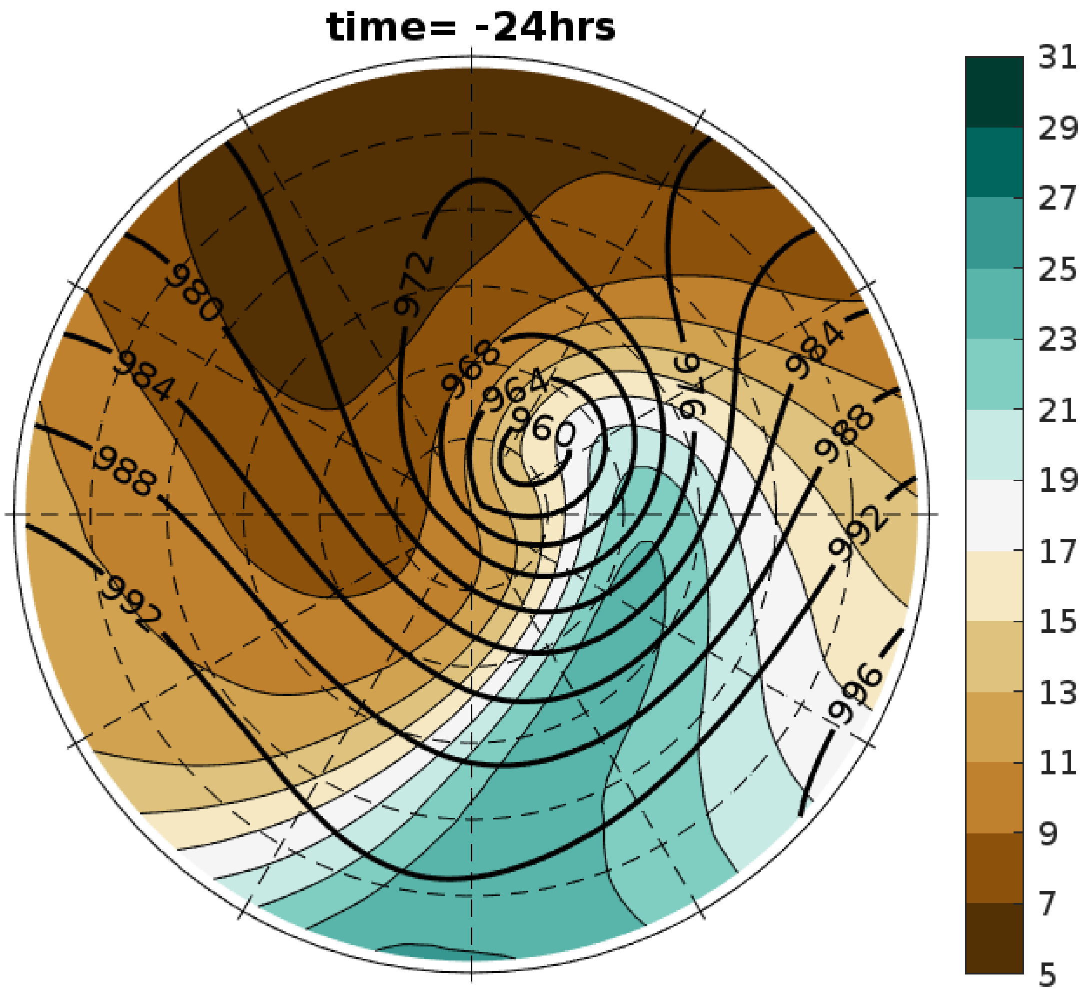
Black contours: surface pressure every 4 hPa



Composite cyclone t=-24 hrs

Shading show total column water vapour

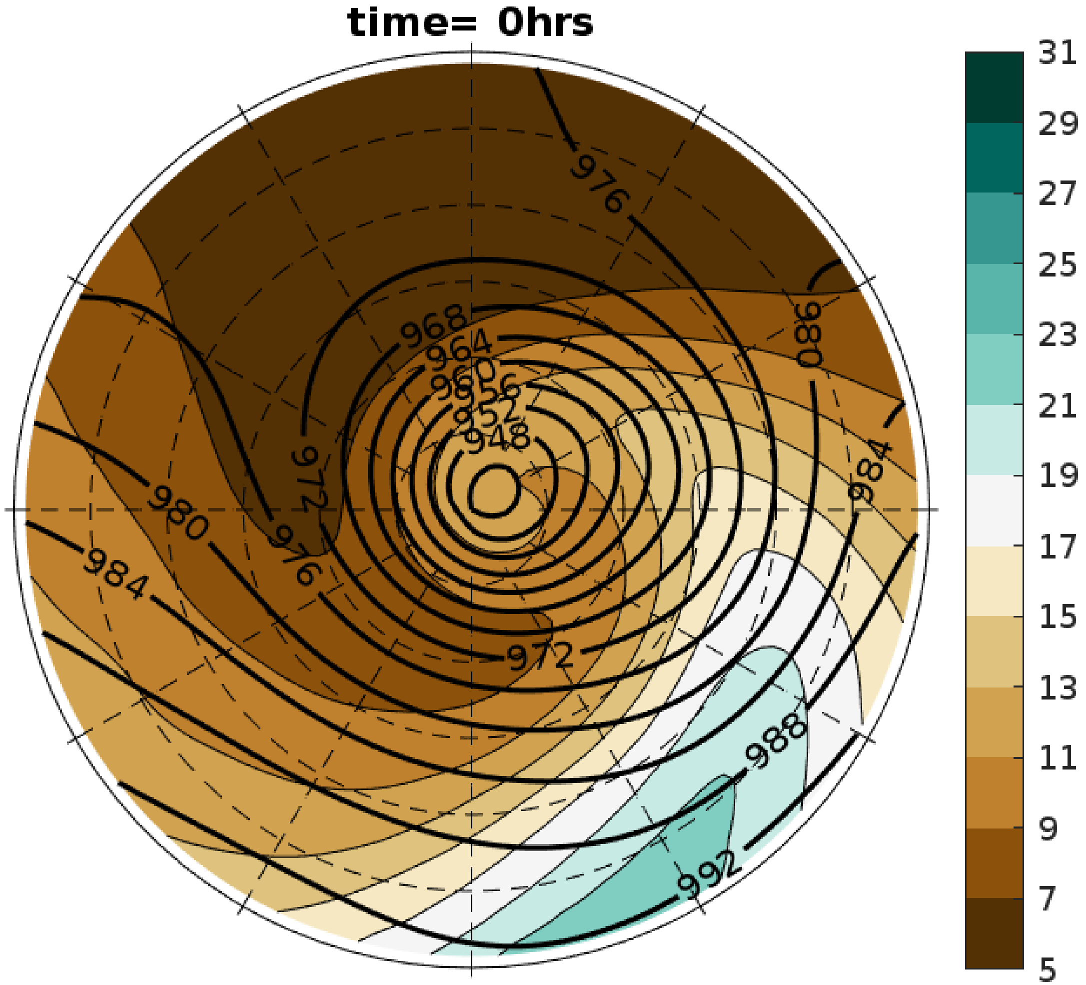
Black contours: surface pressure every 4 hPa



Composite cyclone t=0 hrs

Shading show total column water vapour

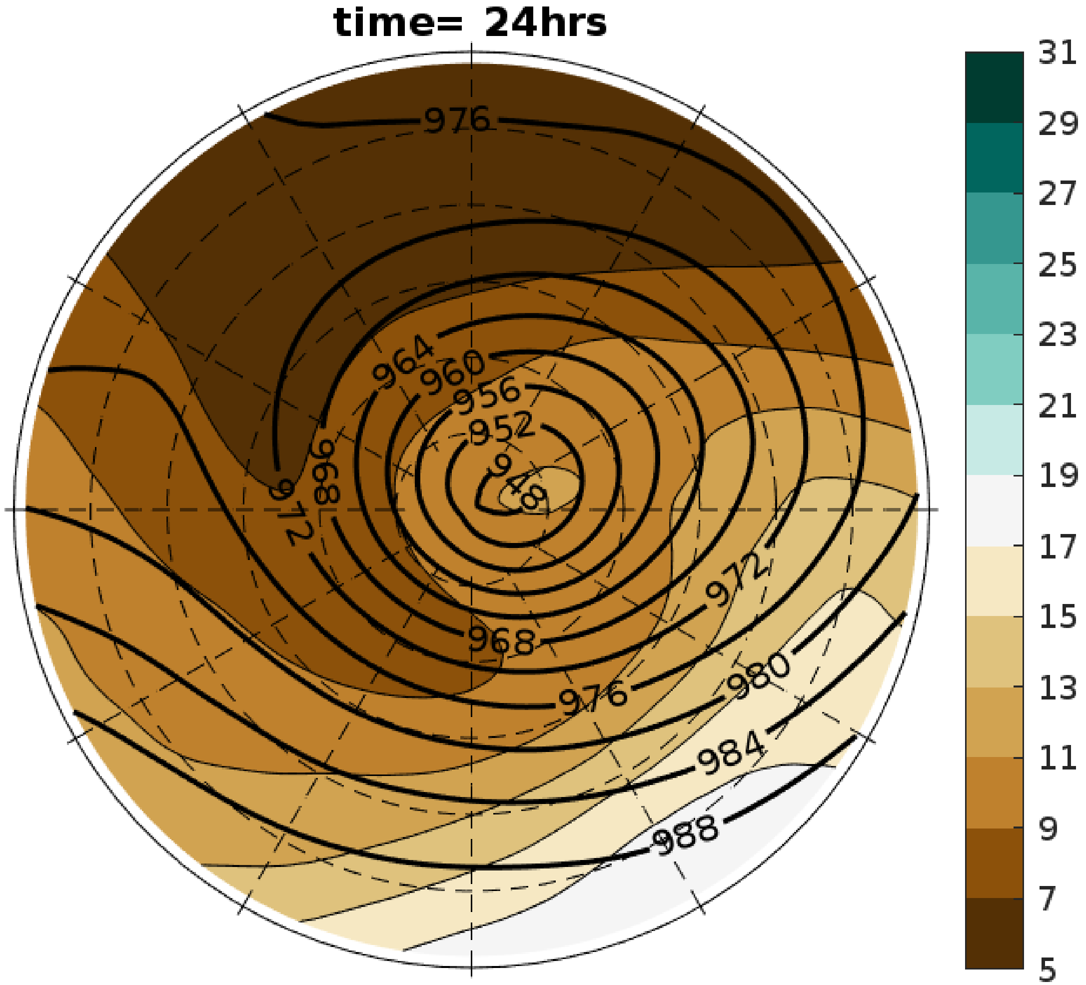
Black contours: surface pressure every 4 hPa



Composite cyclone t=+24 hrs

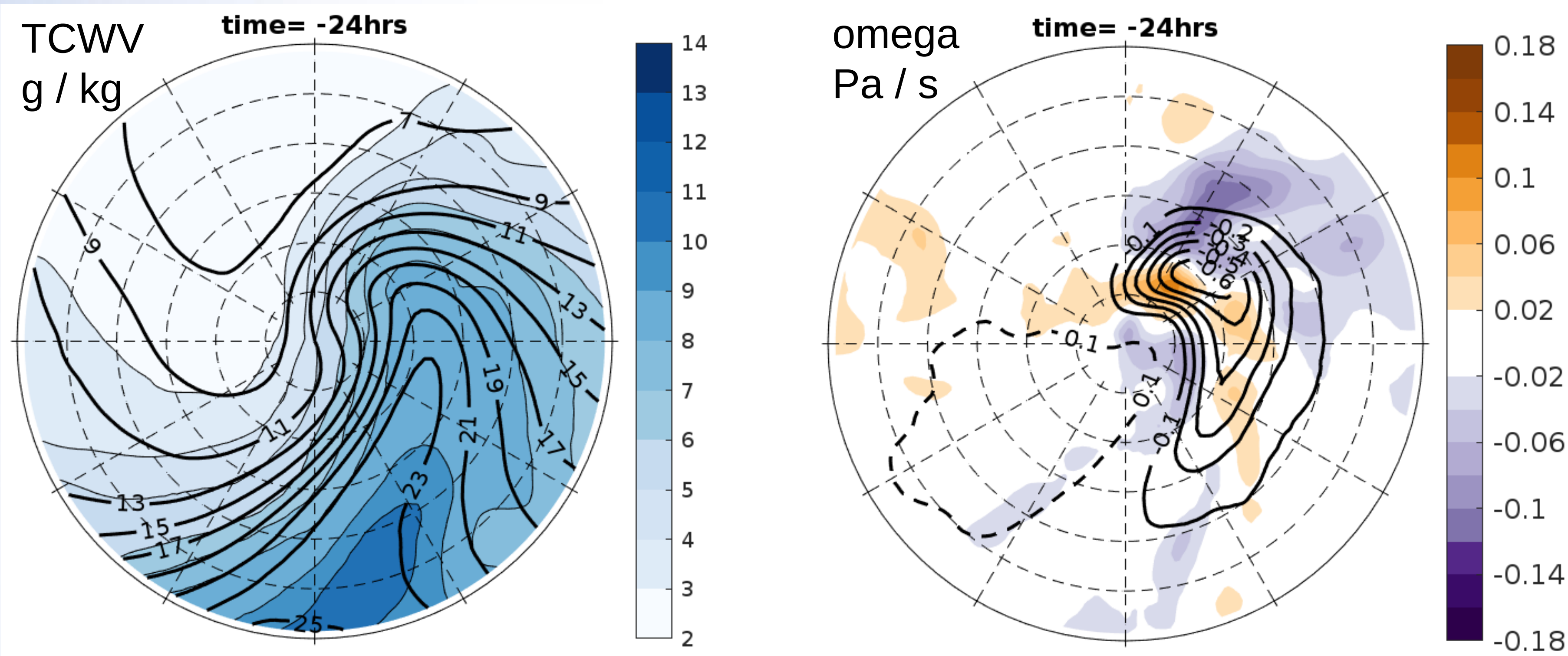
Shading show total column water vapour

Black contours: surface pressure every 4 hPa



Contours show control, shading the difference (SST4 - control)

Moisture and vertical motion (700hPa)

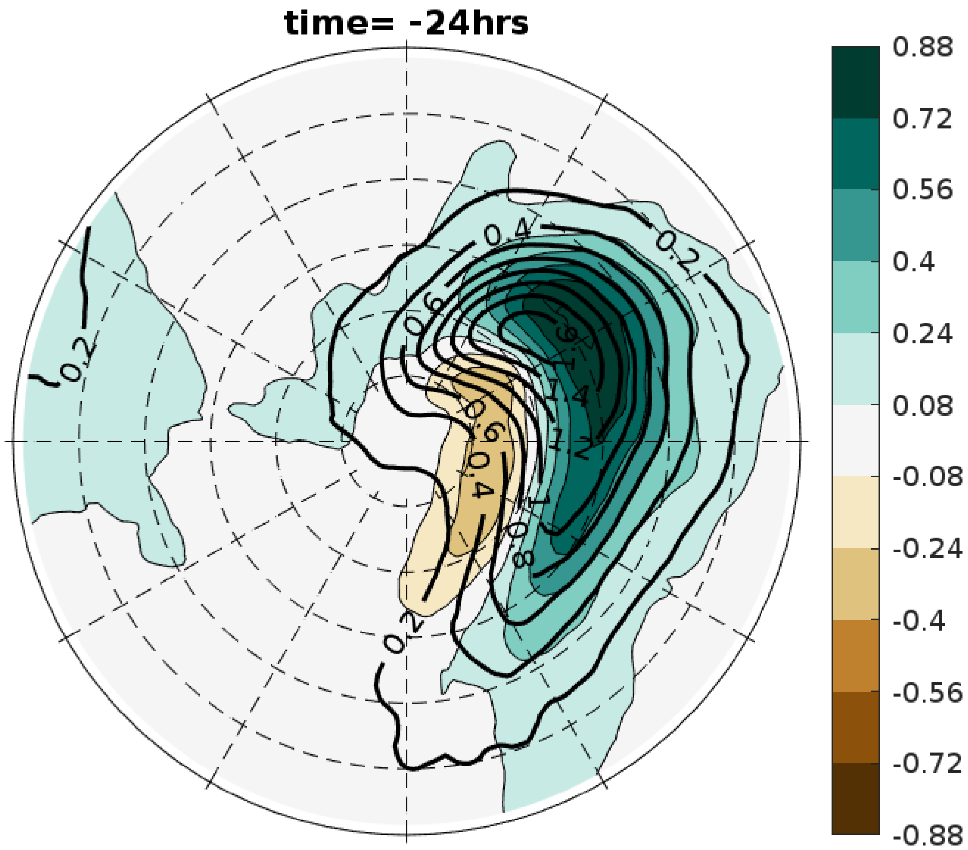


Moisture increases everywhere

Stronger ascent (purple)

Change in location of ascent – farther poleward

Precipitation



Total Precipitation
mm / day

Precipitation has a net increase

Change in the location (relative to the cyclone centre) of heaviest precipitation

Change in precipitation is strongly related to changes in ascent

What are the reasons for the changes in vertical motion?

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Omega Equation
Identify physical cause of vertical motion

$$\sigma_0(p)\nabla^2\omega + f^2\frac{\partial^2\omega}{\partial p^2} = f\frac{\partial}{\partial p}\left(\mathbf{V}\cdot\nabla\left(\zeta+\mathbf{f}\right)\right) + \frac{R}{p}\nabla^2\left(\mathbf{V}\cdot\nabla\mathbf{T}\right) + \frac{R}{c_p p}\nabla^2 Q.$$

Differential vorticity advection

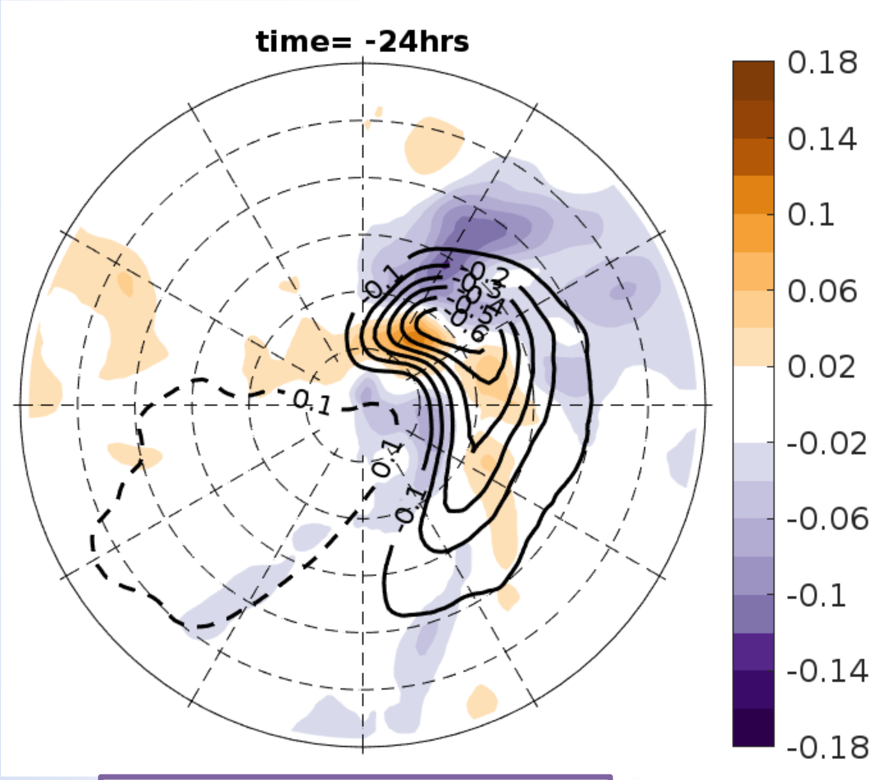
Thermal advection

Diabatic heating / cooling

- Use the full wind rather than the geostrophic wind
- Use the full relative vorticity instead of the geostrophic relative vorticity
- Good agreement (0.9 correlation coefficient) between model omega and total “QG” omega

Compare full and QG total vertical motion

Contours show control, shading the difference (SST4 - control)



Full vertical motion
700 hPa

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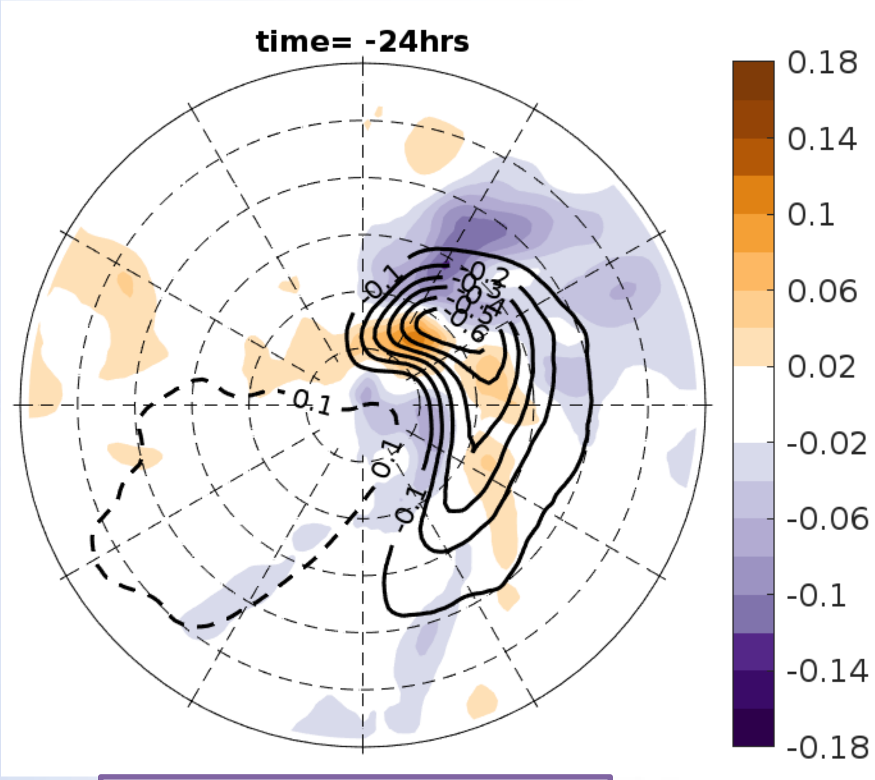

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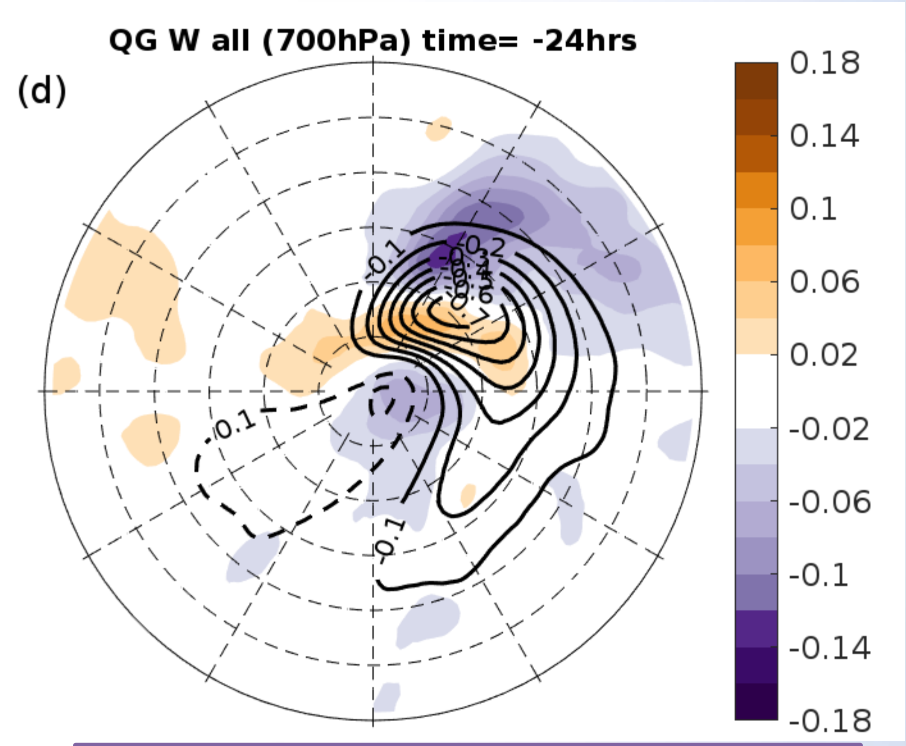

Quasi-Geostrophic vertical motion
700 hPa

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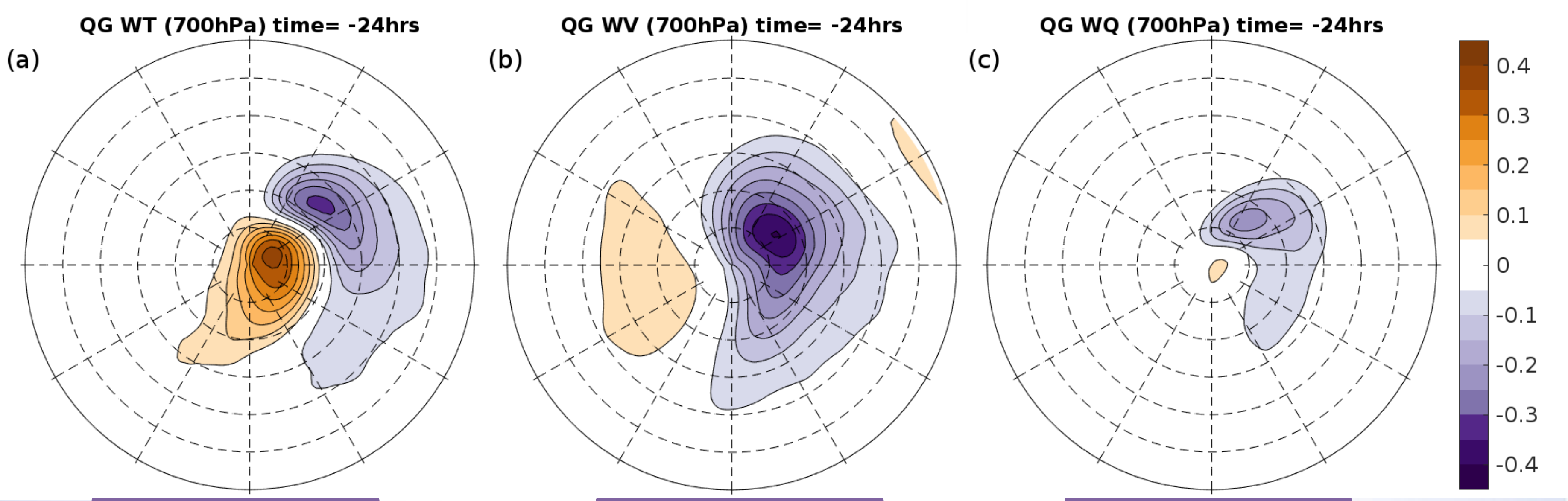
Quasi-Geostrophic vertical motion



Thermal advection

Vorticity advection

Diabatic term

Control simulation: vertical motion at 700hPa
24 hours before time of maximum intensity
Purple = ascent, Brown = descent

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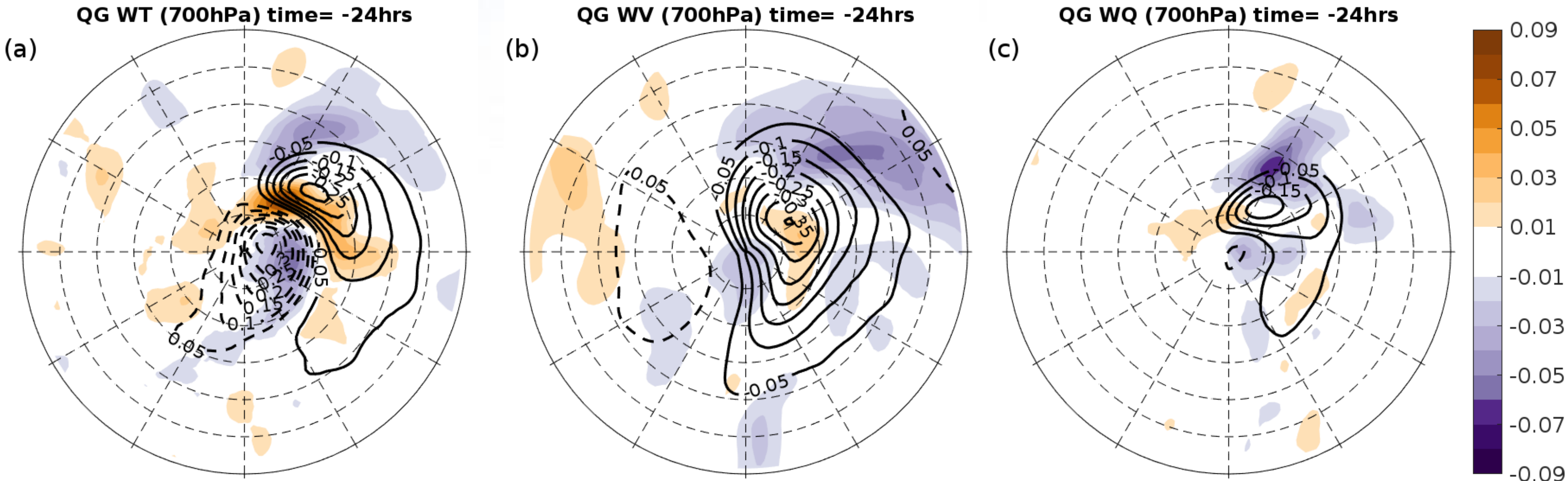
Change due to warming (700hPa)



Thermal advection

Vorticity advection

Diabatic term

Purple = stronger ascent in warmer experiment

Ascent ahead of the warm front increases and moves polewards due to a combination of all processes

Area of ascent due to thermal advection is the main cause of the dipole

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Conclusions

- Warming SSTs does not change the median intensity of extra-tropical cyclones
- The variability in extra-tropical cyclone intensity increases

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- When SSTs are warmed, precipitation
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  - moves farther away from the cyclone centre
  - Covers a larger area

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- When SSTs are warmed, precipitation
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- Vertical motion increases ahead of the warm front due to a combination of processes
- Not just diabatic heating, changes in the structure of the cyclone as well

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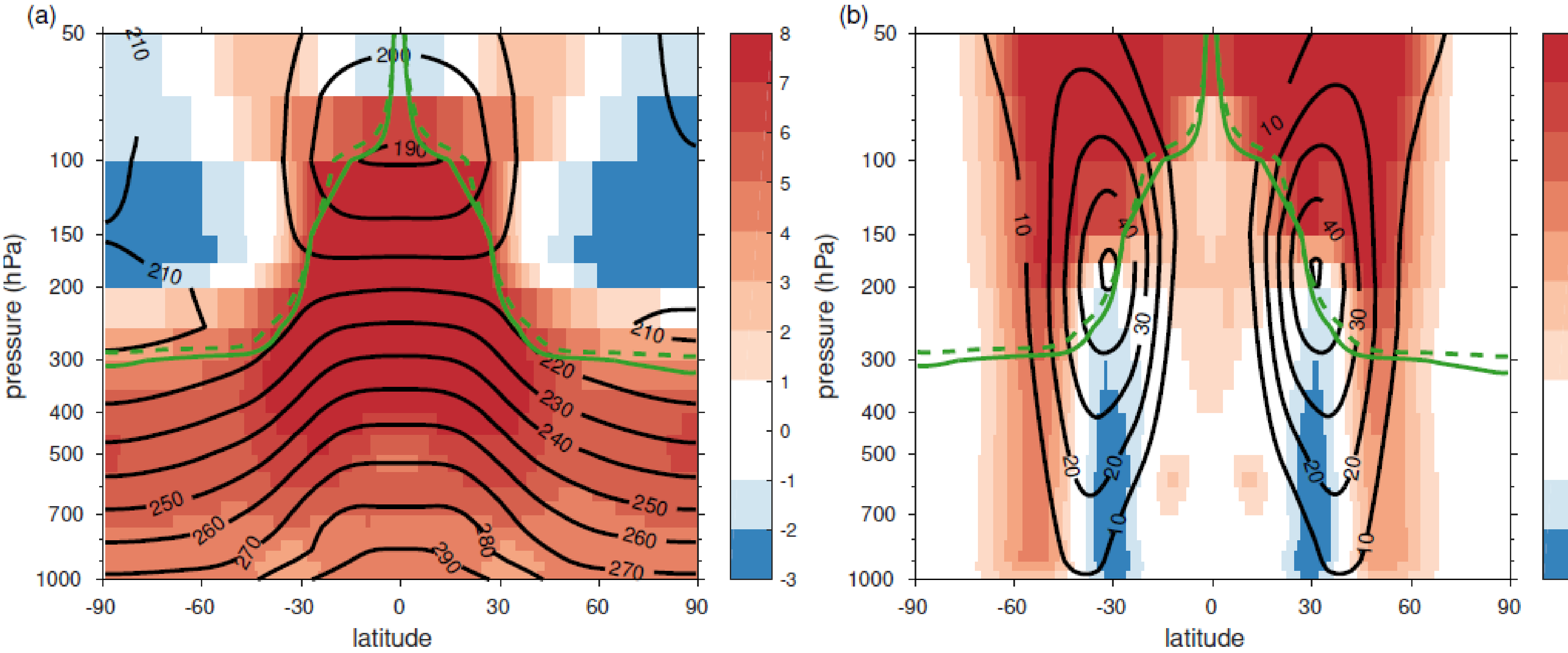
Zonal mean and response



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Strongest 200 storms

	All Cyclones		Strongest 200	
	control	SST+4K	control	SST+4K
Median 850-hPa vorticity	5.94	5.75	11.24	11.56
Genesis Latitude	44.2	46.2	37.8	38.2
Lysis Latitude	51.4	53.3	51.2	55.0

- Warming increases the median vorticity of the strongest 200 extra-tropical cyclones (opposite to when all ETCs are considered)

- The strongest ETCs form more equatorward than the average cyclone

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TABLE 2. Cyclone statistics from CNTL and SST4. Relative vorticity values are $\times 10^{-5}s^{-1}$. For vorticity values the relative change ((SST4-CNTL)/CNTL) is given as a percentage. For latitudes the absolute change is given.

		All Cyclones			Strongest 200 Cyclones		
	Diagnostic	CNTL	SST4	Change	CNTL	SST4	Change
intensity	Number of tracks / cyclones	3581	3462	-3.3%	200	200	0%
	Mean maximum 850-hPa vorticity	6.11	6.07	-0.7%	11.55	11.87	+2.8%
	Median maximum 850-hPa vorticity	5.94	5.75	-3.2%	11.24	11.56	+2.8%
	Standard deviation of maximum 850-hPa vorticity	2.55	2.80	+9.8%	1.00	1.22	+22%
location	median genesis latitude	44.2°N	46.2°N	2.0°	37.8°N	38.2°N	+0.4°
	median lysis latitude	51.4°N	53.3°N	1.9°	51.2°N	55.0°N	+3.8°
	median dlat (lysis -genesis latitude)	6.2°	6.0°	-0.2°	13.7°	16.7°	+3.0°
	median dlat (max vort lat -genesis latitude)	2.9°	2.9°	0°	9.0°	9.3°	+0.3°
	200 threshold	-	-	-	10.44	10.88	+4.2%
	Vorticity of strongest cyclone	-	-	-	15.55	16.80	+8.1%

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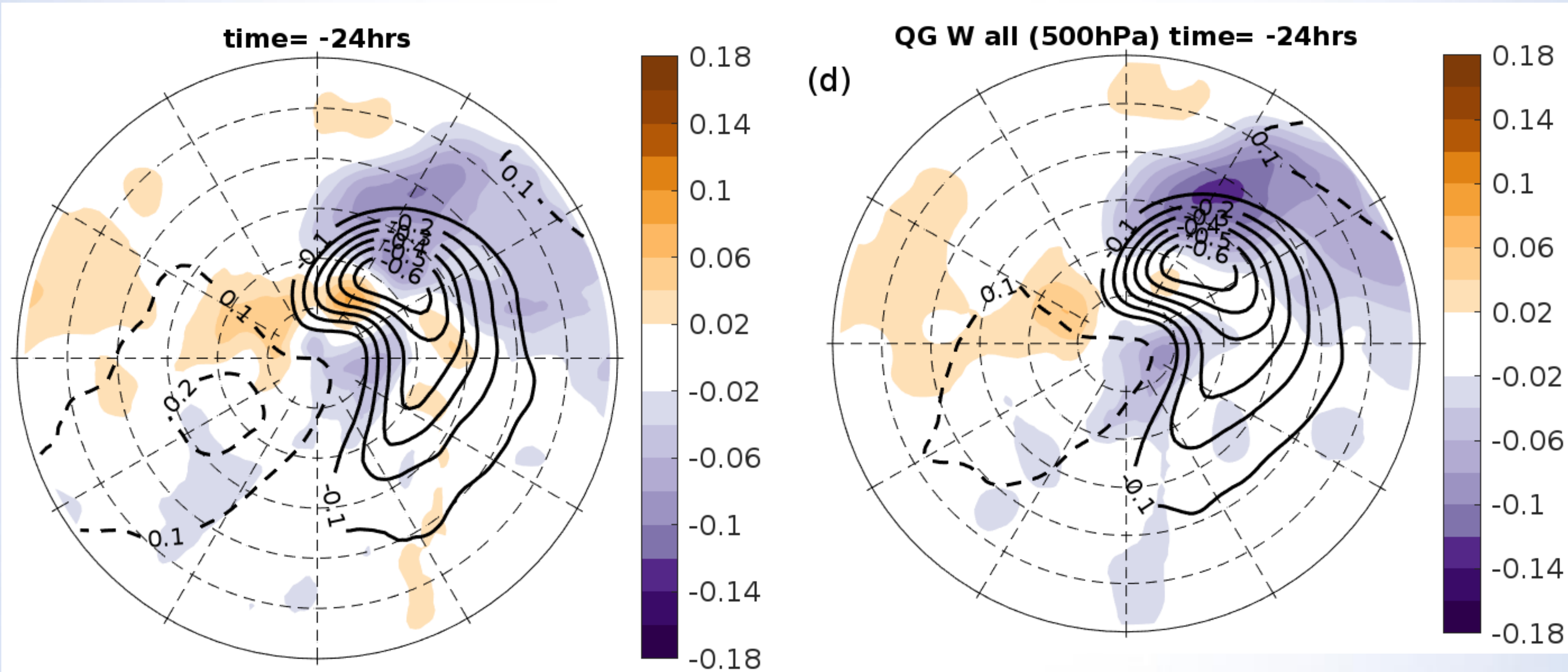
Total change in full and QG omega at 500hPa



Full vertical motion
700 hPa

Quasi-Geostrophicvertical motion
700 hPa

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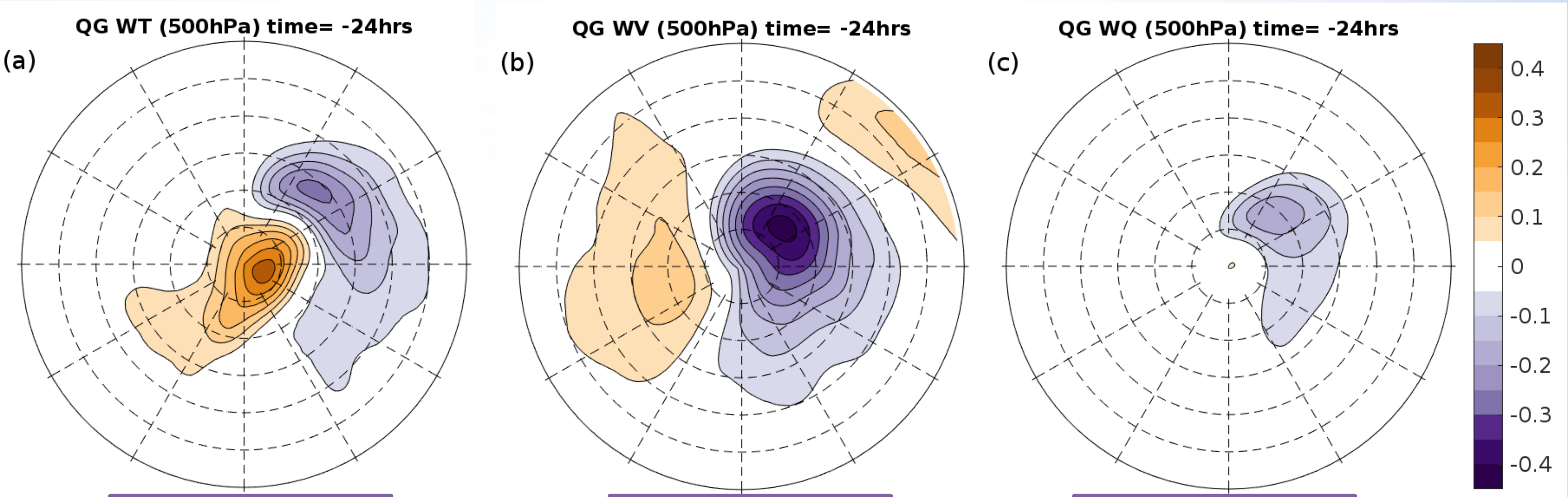
QG vertical motion (500hPa)



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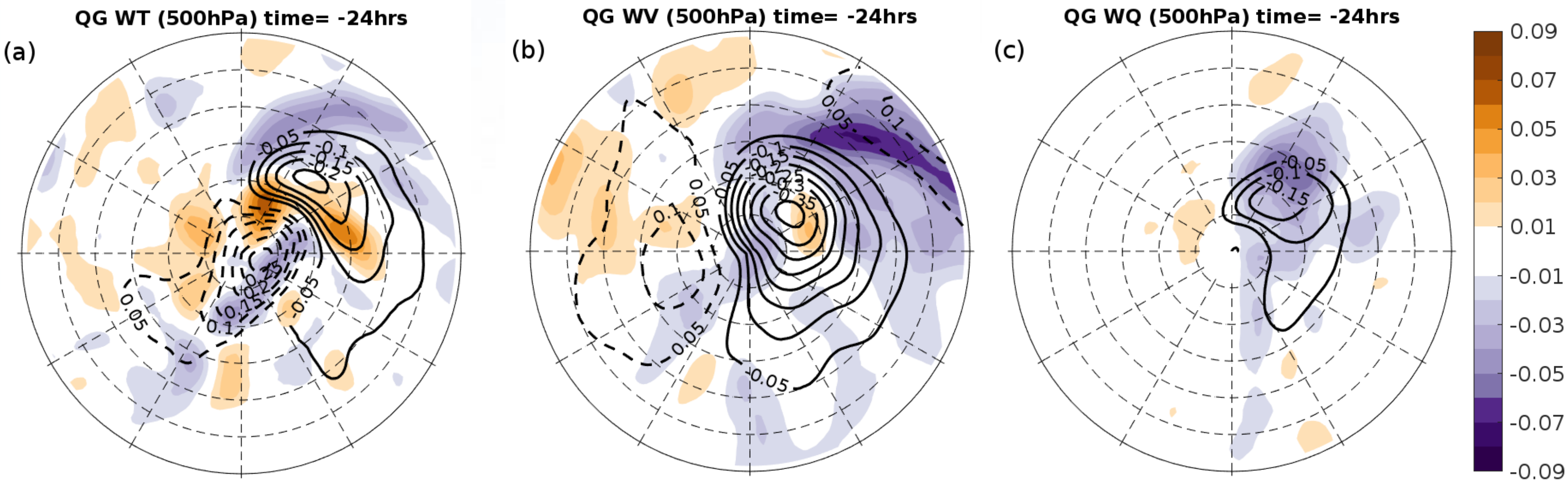

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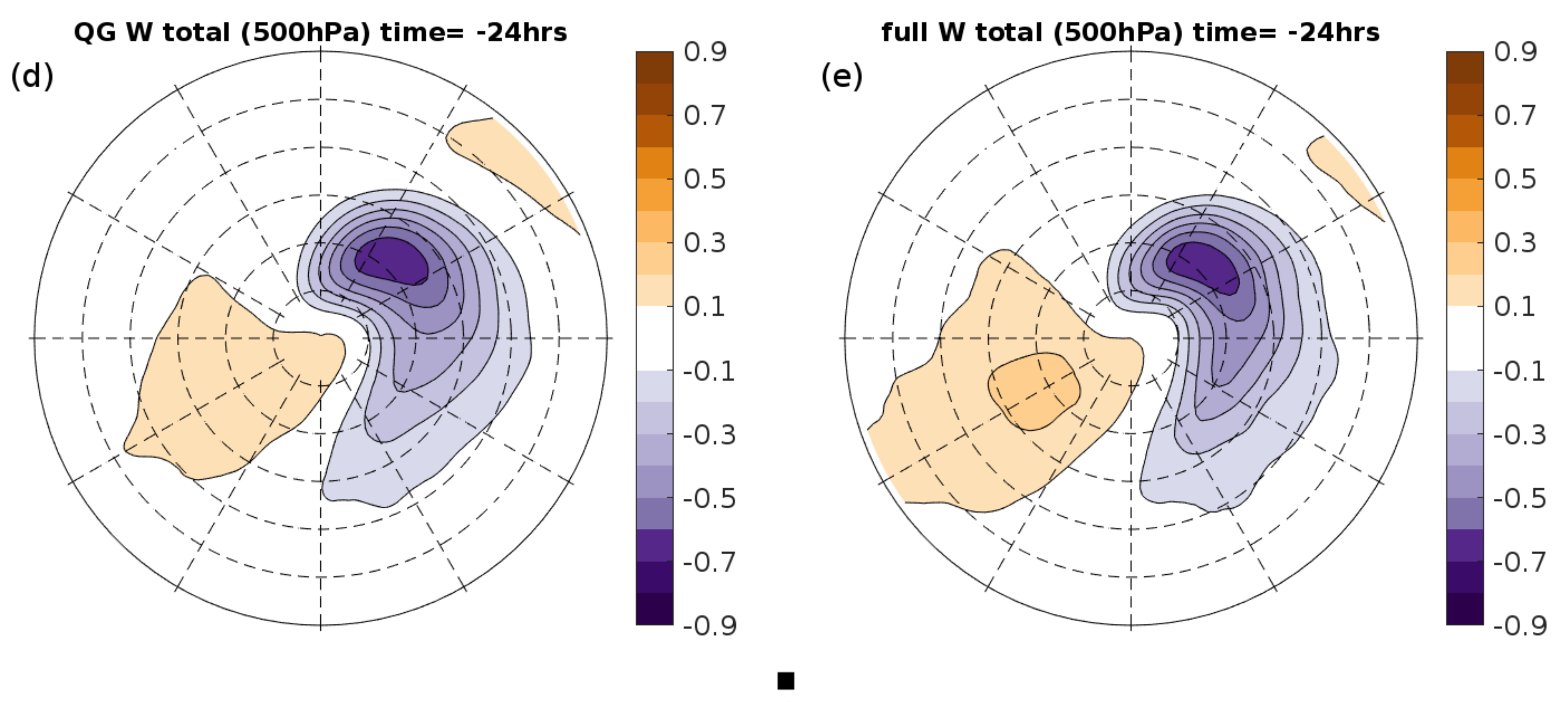
Ascent due to diabatic heating increases and also moves polewards

Good agreement between total vertical motion and QG vertical motion



Control at 500 hPa

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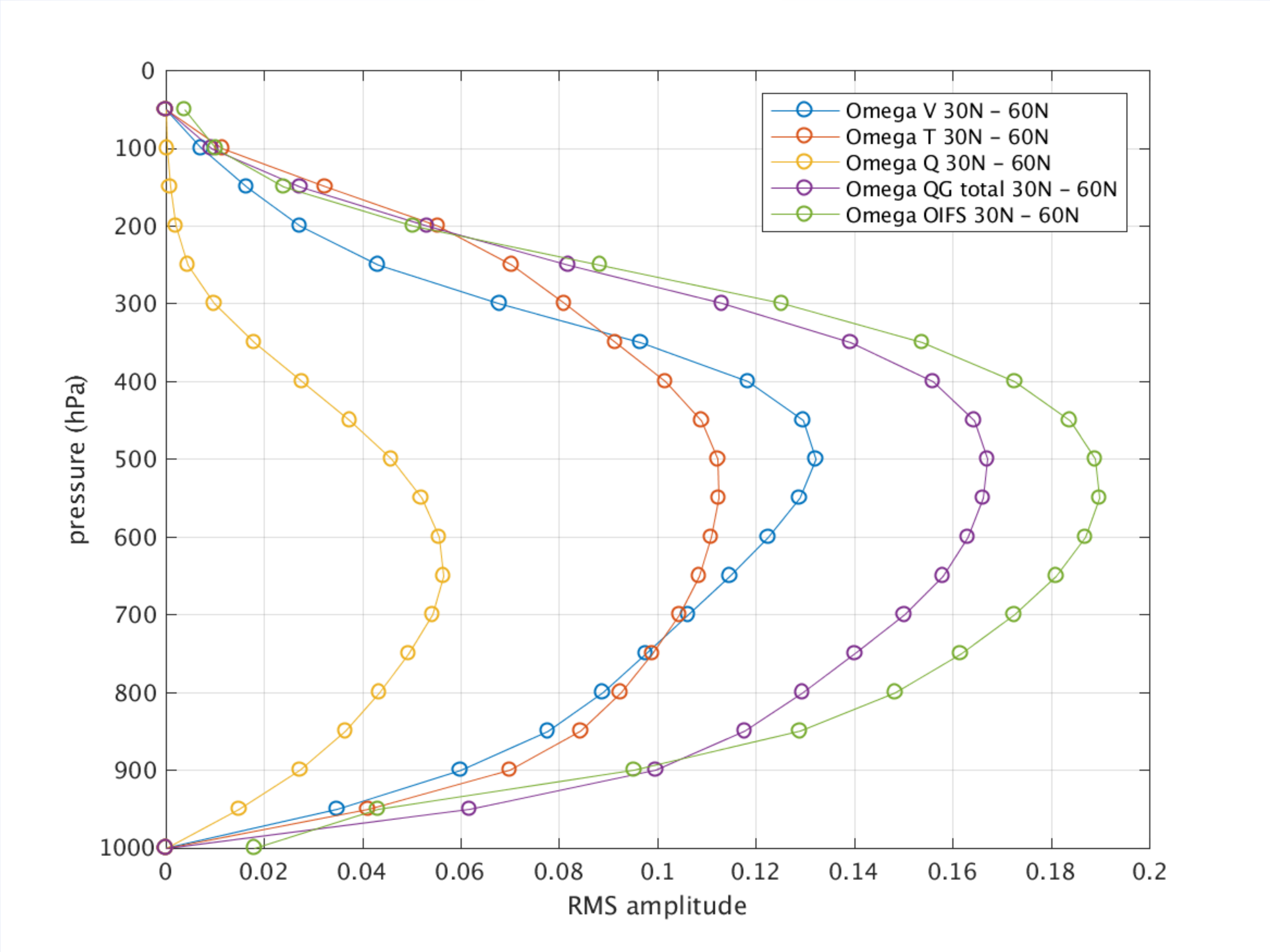
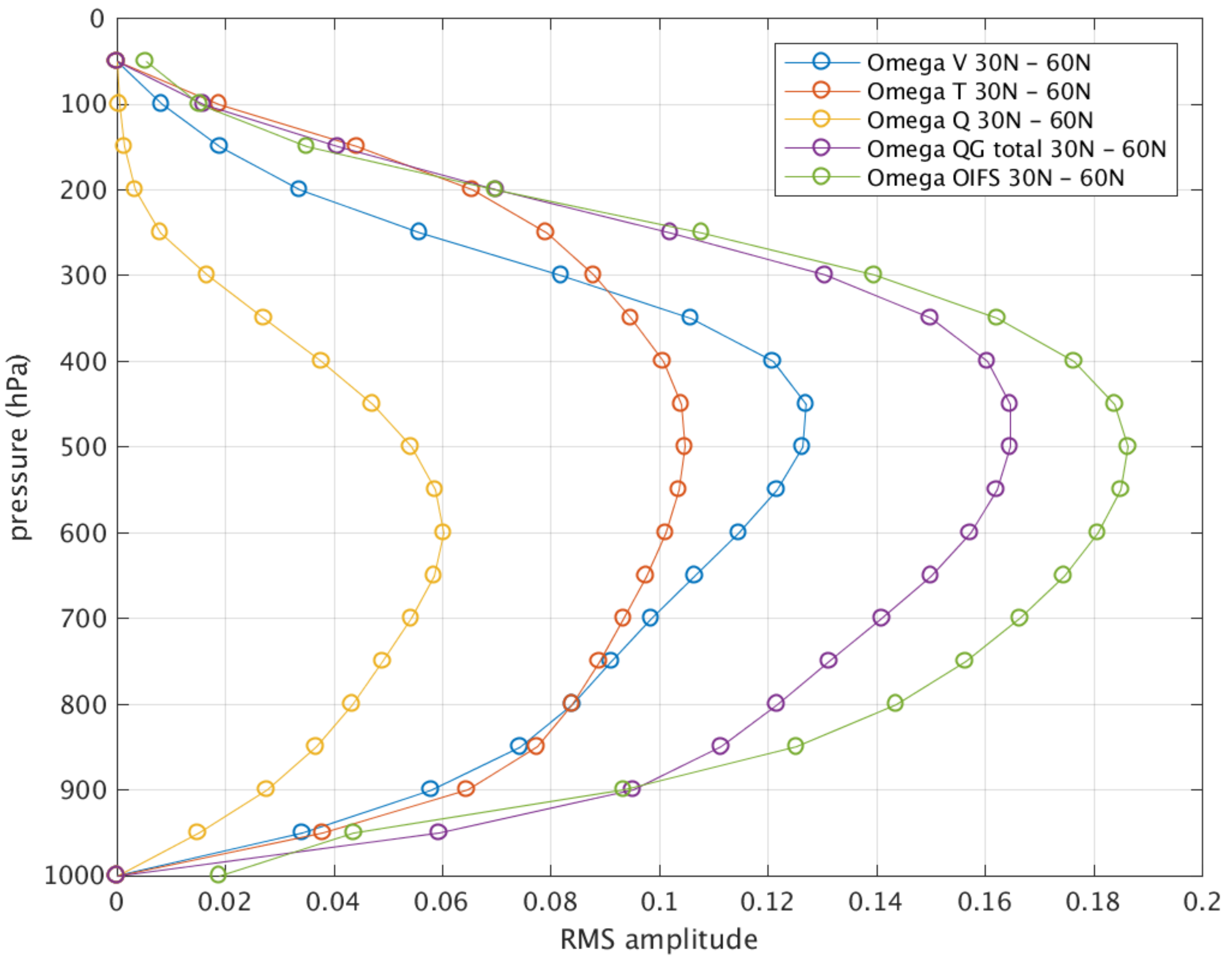
Root Mean Square amplitude of omega averaged over 3 years from the **control** simulation in the mid-latitudes (not just in cyclones)



Root Mean Square amplitude of omega averaged over 3 years from the **SST+4K** simulation in the mid-latitudes (not just in cyclones)



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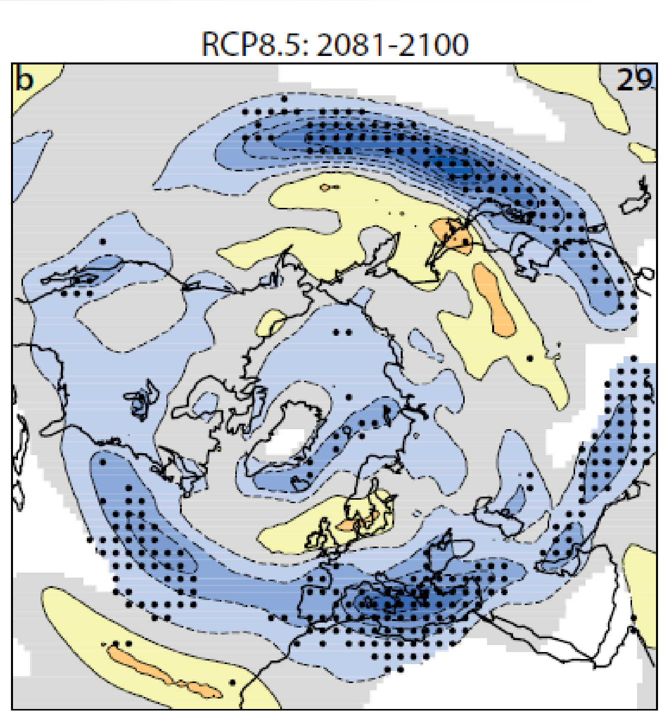
Why study changes to cyclone structure?



Change in winter extra-tropical storm track density (2081 – 2100) – (1986-2005). Multi-model ensemble mean

Many studies have considered how the number, intensity or location of extra-tropical storms may change ….. BUT…

"*substantial uncertainty* and thus low confidence remains *in projecting changes in NH winter storm tracks*"

Stippling: where 90% of models agree on the sign of the change.

Northern Europe: large uncertainties

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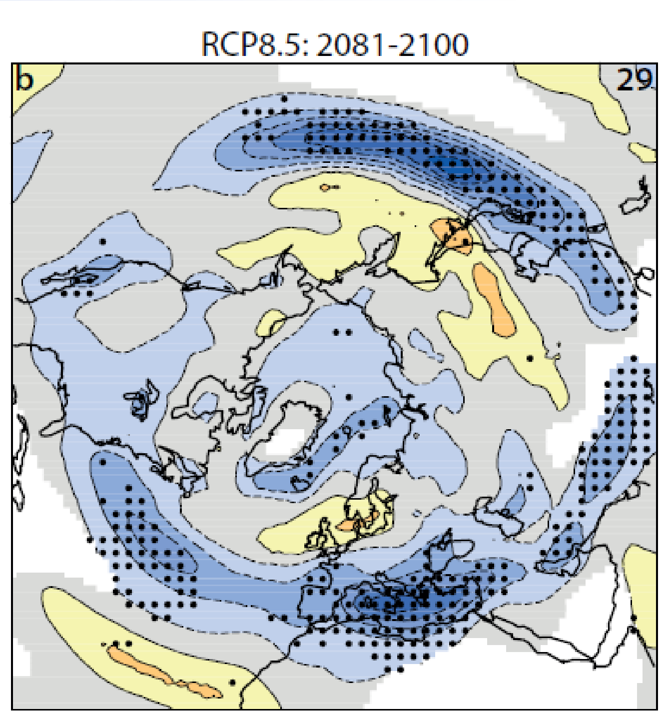

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Northern Europe: large uncertainties

Few studies have considered how cyclone structure may change

May help understand changes in bulk statistics