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Midlatitude Storms and Atmospheric Jets in the CESM1.3: Resolution Dependence, Coupling Sensitivity, and Projected Future Change

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CESM1.3 Simulations

0.25°atmos/land –only (30 years)

- ~70M core-hours 4.4M node-hours
- 4 present day (1979-2012)
- 8 future RCP8.5 scenarios (2070-2099)

1°atmos/land –only (30 years)

- 596K core-hours 37K node-hours
- 3 present day (1965-2005)
- 3 future RCP8.5 scenarios (2070-2099)

Fully-coupled 1° atmos/land - 1° ocn/ice

- 3.2M core-hours 202K node-hours
- 1 Pre-industrial control (400 yrs)
- 3 Historicals (1850-2005)
- 3 future RCP8.5 (2006-2100)

Fully-coupled 0.25° atmos/land - 1° ocn/ice

- ~300M core-hours 18.8M node-hours
- 1 Pre-industrial control (200 yrs)
- 1% CO2 and 4xCO2 (140 yrs)
- 3 Historicals (1850-2005)
- 3 future RCP2.6 (2006-2100)
- 1 future RCP4.5 (2006-2100)
- 1 future RCP6.0 (2006-2100)
- 3 future RCP8.5 (2006-2100)

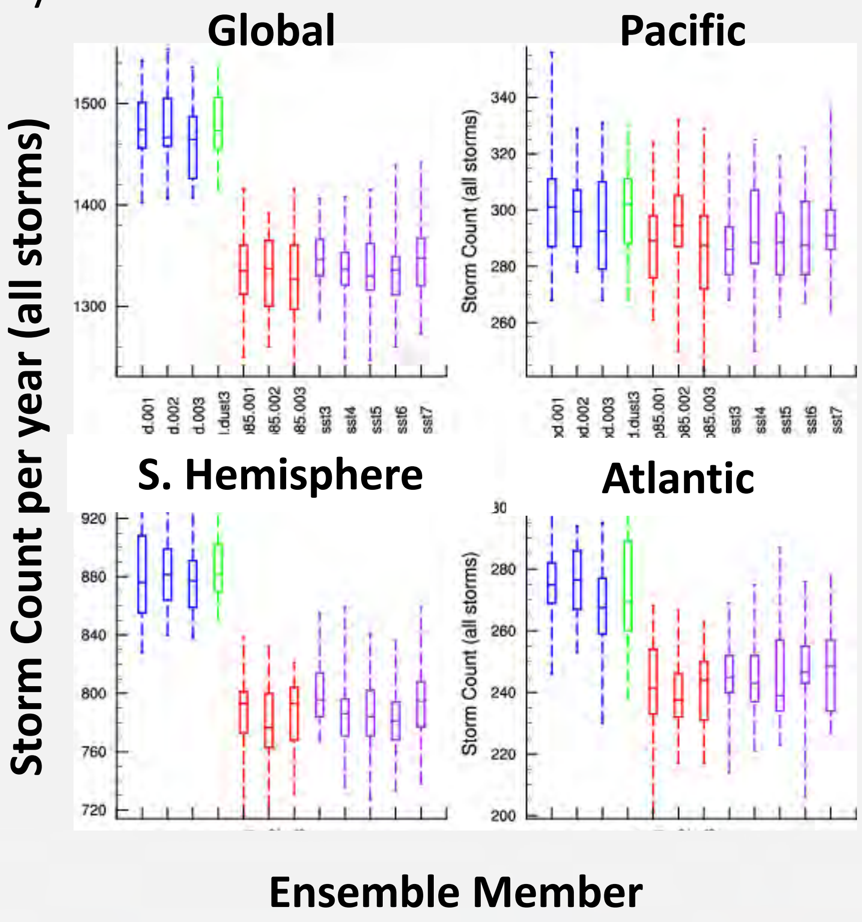
Fully-coupled 0.25° atmos/land – 0.1° ocn/ice

- ~200M core-hours 12.5M node-hours
- 1 present-day control (135 yrs)
- 1 early century (2000-2005)
- 1 future RCP8.5 (2006-2100)

- 1 PI control (500 yrs)
- 10 historical + RCP8.5 (1850-2100)

Present Day and Future ETC Storm Count

0.25° atmos/land only

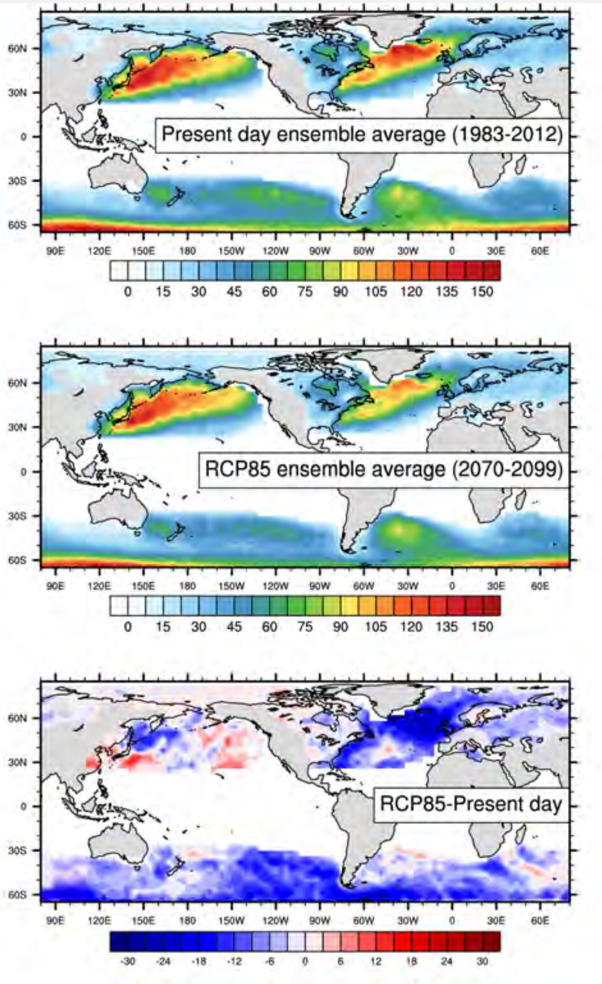


Present Day 1983-2012
Present Day 1983-2012 (modified dust)
Future RCP8.5 2070-2090
Future RCP8.5 2070-2090 (modified SST)

Present Day and Future (0.25deg)

Track Density

All storms



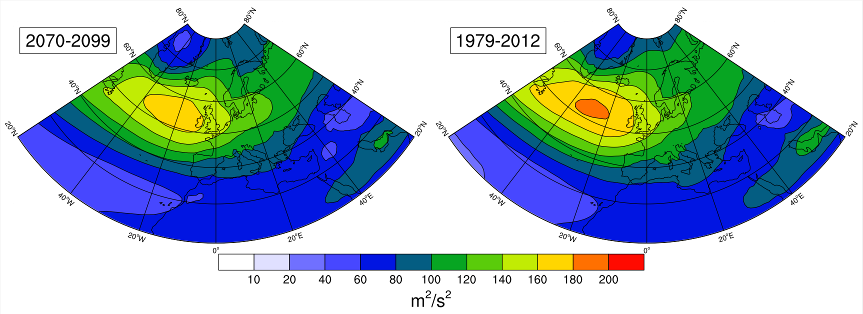
Units are average hours per year in which a storm is found within a 4° x 4° gridbox

Eddy Kinetic Energy (500mb) Northern Hemisphere

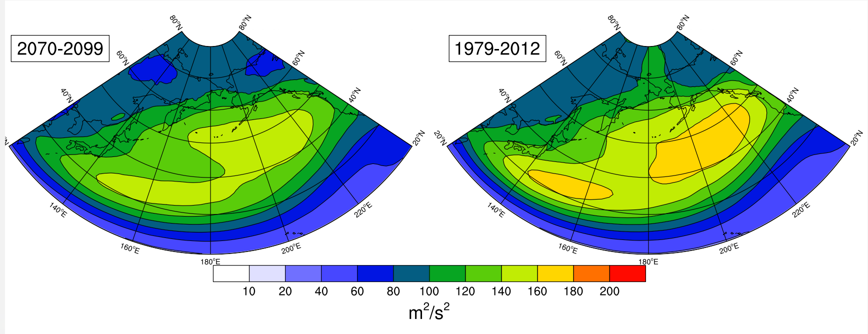
Future

Present Day

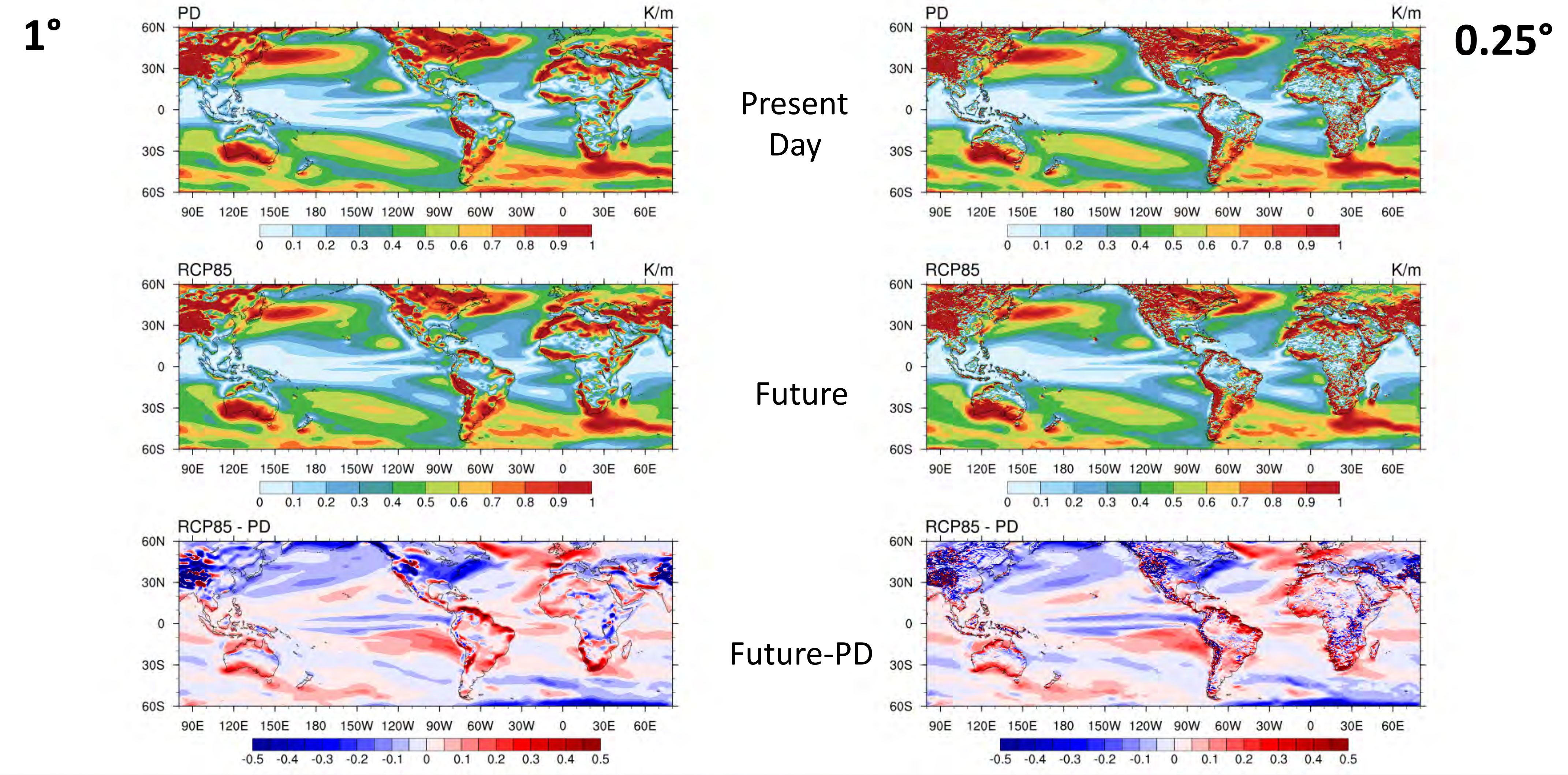
North Atlantic



North Pacific



Latitudinal Temperature Gradient (dT/dy) – 950mb



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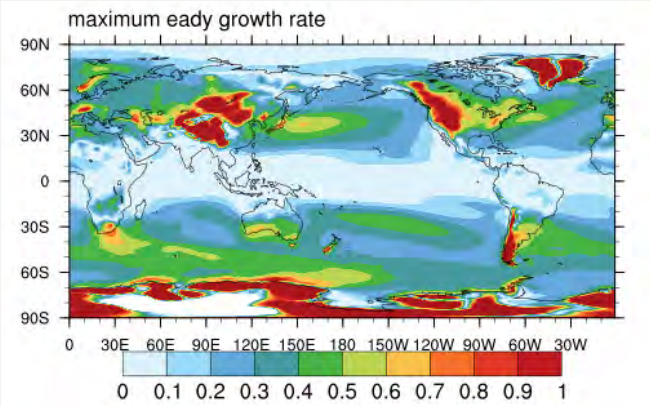
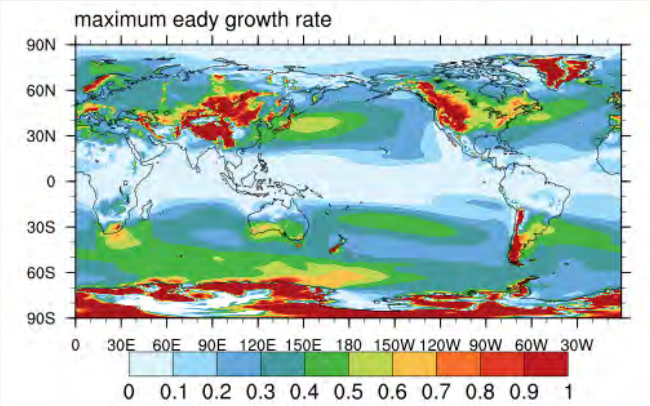
Eady Growth Rate

$$\text{Eady Growth Rate} = \frac{0.31 * g * |f| * |du/dz|}{(g/\theta * d\theta/dz)^{1/2}}$$

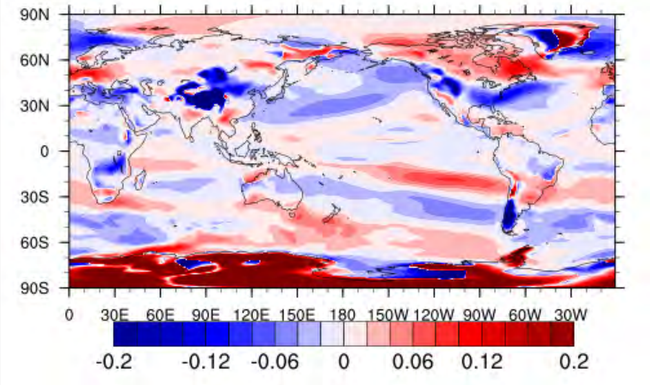
1°

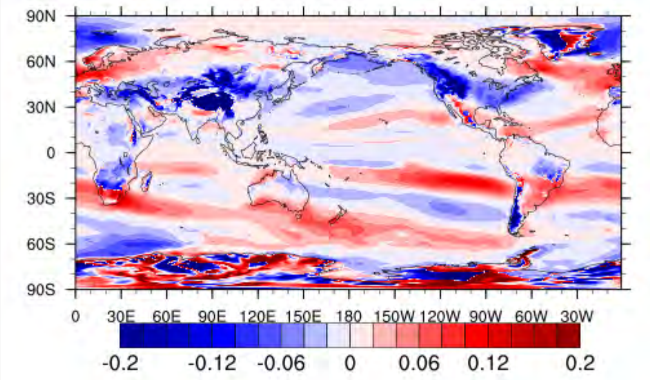




0.25°

Present Day





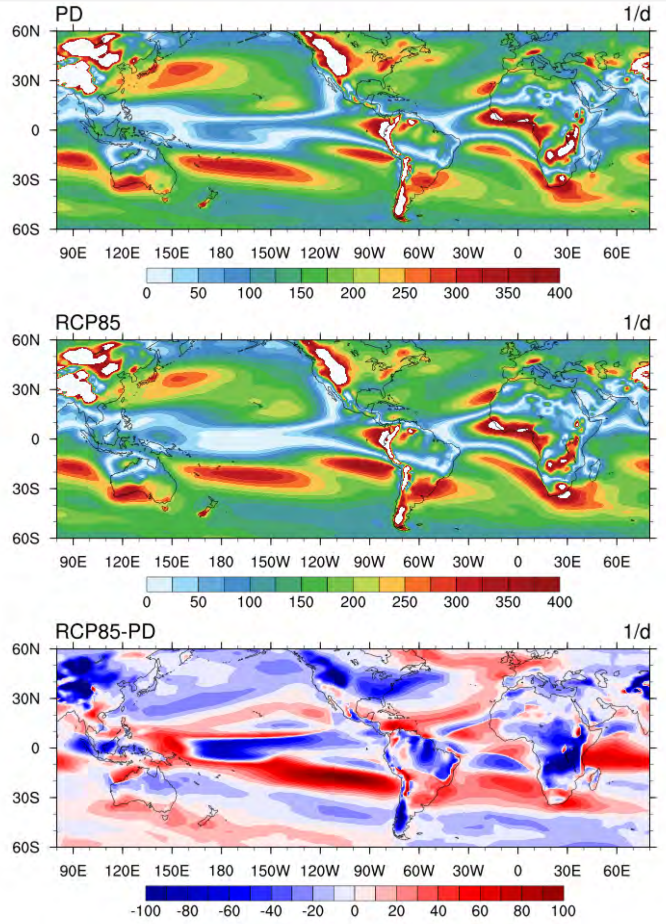
Future-PD

Eady Growth Rate Terms

Vertical Wind Shear (du/dz)

Vertical Temperature Gradient (dθ/dz)

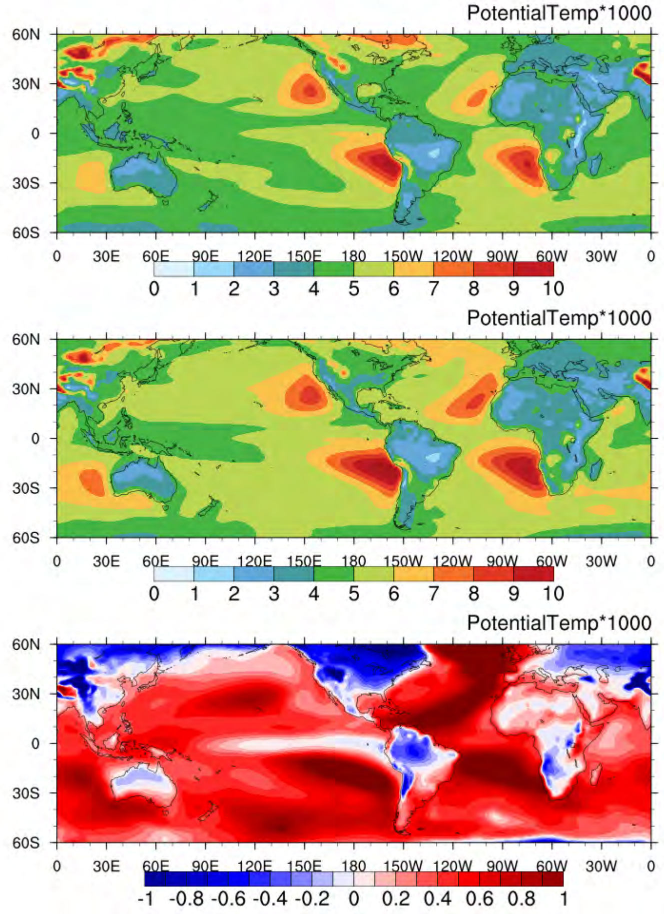
1°



Present Day

Future

Future-PD



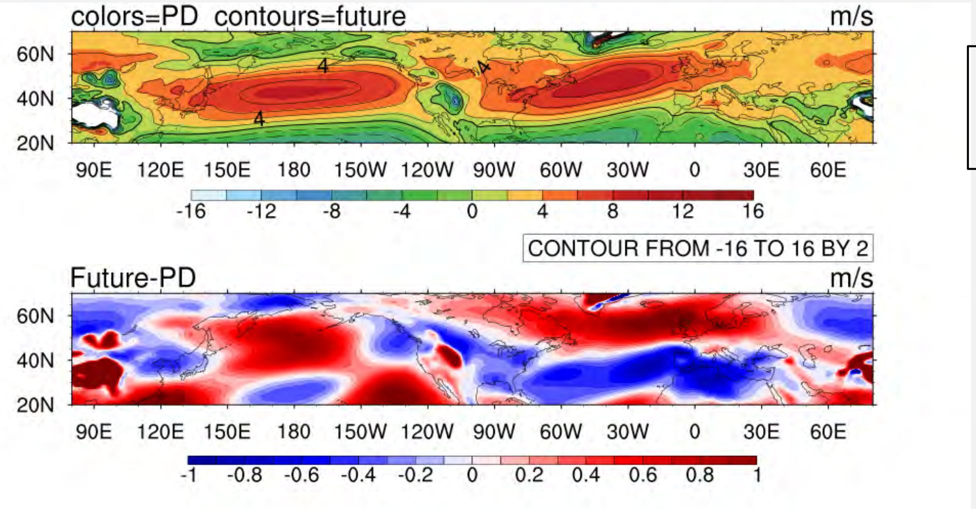
1°

Eady increases
Stability decreases

Eady decreases
Stability increases

Zonal Wind at 850mb
Northern Hemisphere

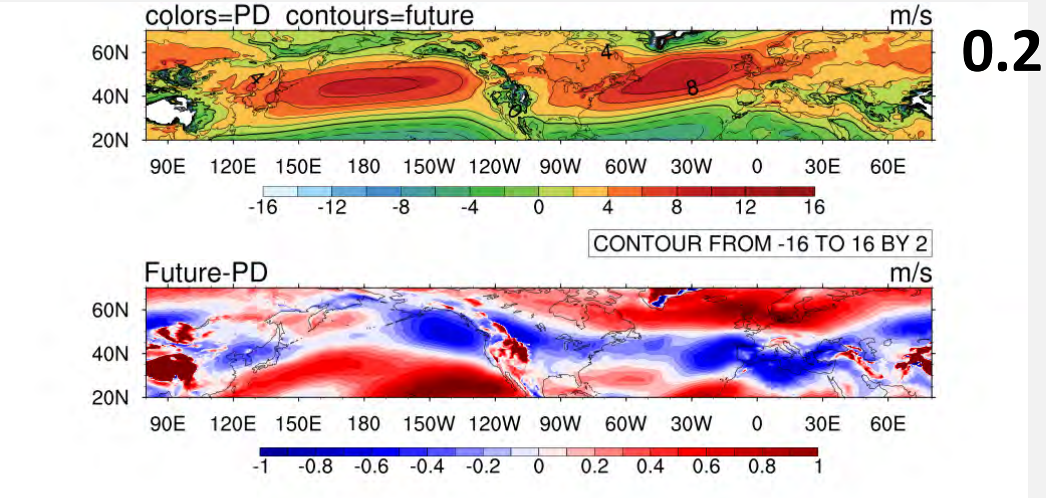
1°



colors = PD
contours = future

Future-PD

0.25°



Southern Hemisphere Jet

Assumption: higher horizontal resolution will produce better simulations of midlatitude storm systems, and thus improved representations of storm tracks

- warmer base-state midlatitude sea surface temperatures (Small et al. 2018)
- zonal structure is sensitive to both Tropical SST and teleconnections, as well as midlatitude SST gradients (Inatsu and Hoskins 2004)
- the atmospheric jet stream and low cloud cover are related (Grise and Polvani 2014, Bony et al. 2015, Ceppi and Hartmann 2015).

Model Versions

Coupled

- 1x1_v1.1
- 1x1_v1.3
- 0.25x1_v1.3
- 0.25x0.1_v1.2
- 1d_v1.3
- 0.25d_v1.1
- 0.25d_v1.3

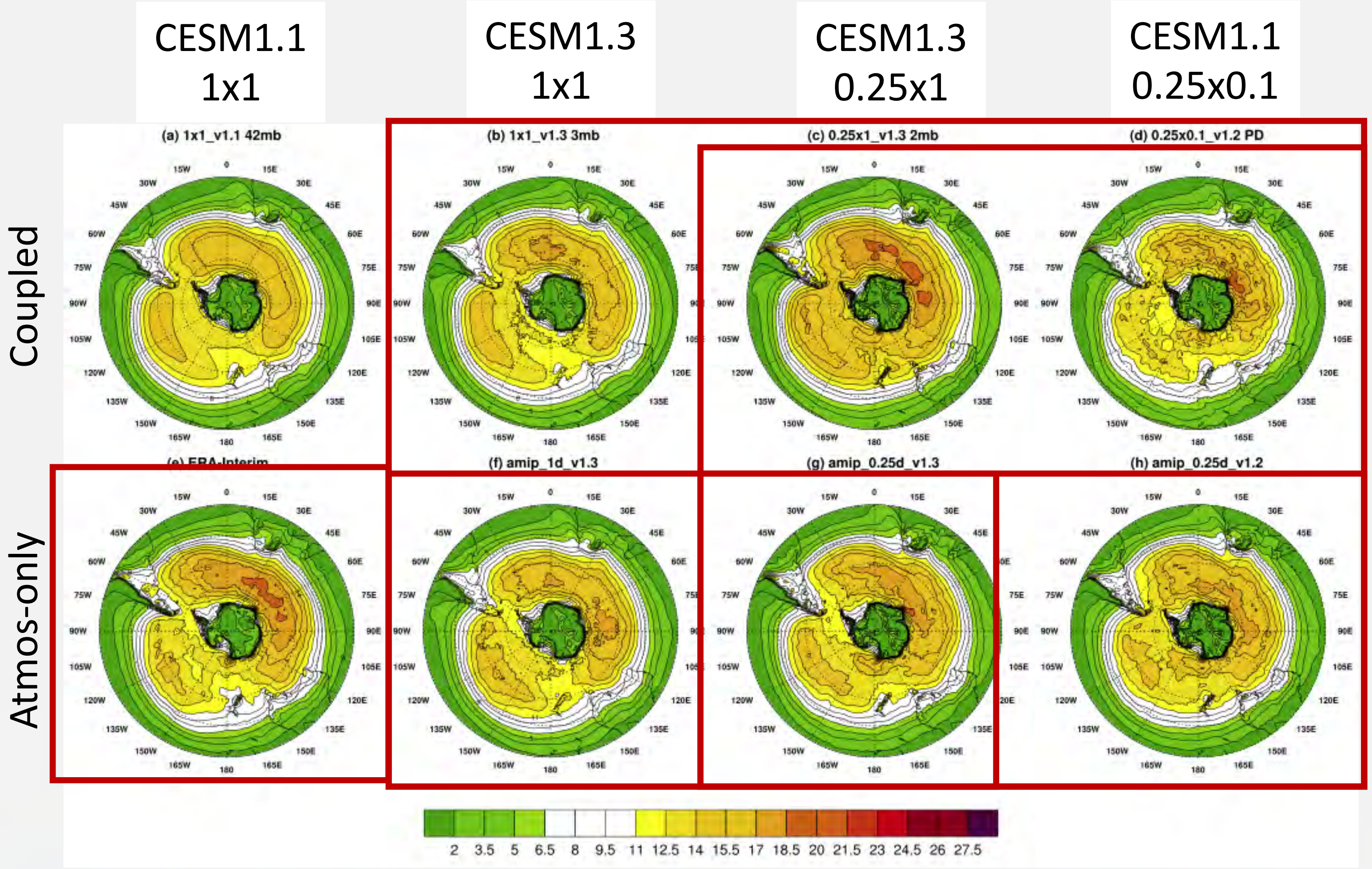
Uncoupled

- 1d_v1.3
- 0.25d_v1.1
- 0.25d_v1.3

Physics Changes

- Dust tuning
- Vertical advection
- Microphysics
- Gravity wave code
- Bug fixes

Southern Hemisphere Jet – Eddy Kinetic Energy 1979-2005 JJA mean

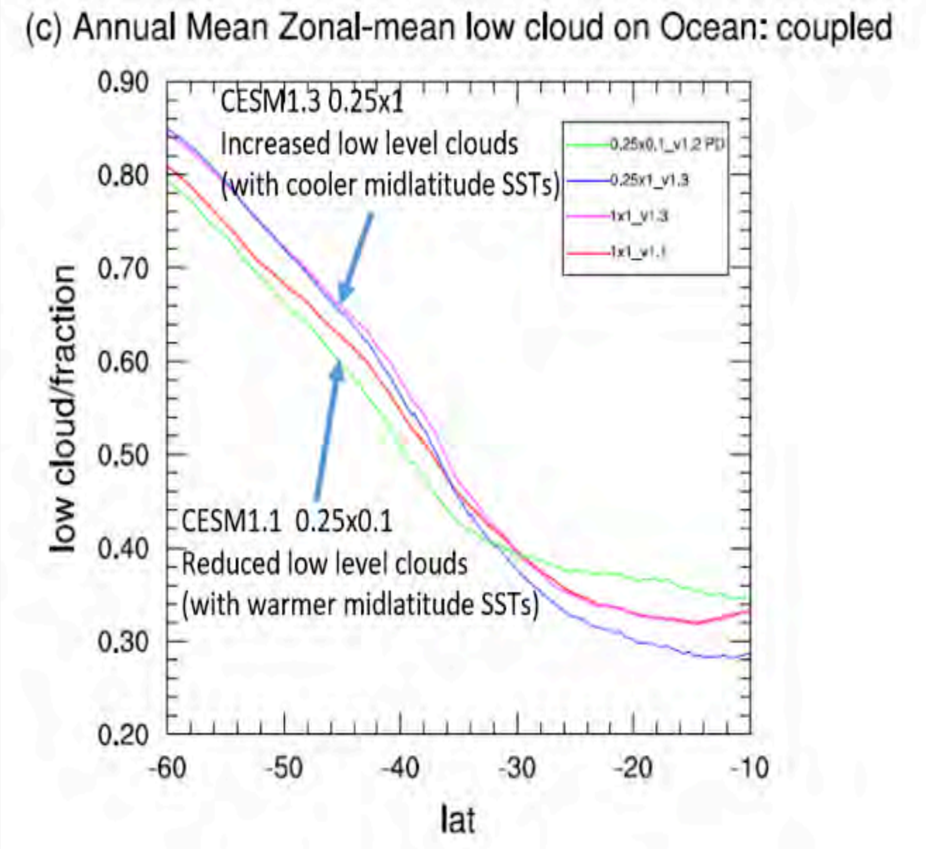


- Same dynamics, different resolution: EKE intensified when resolution increased
- Same resolution, different dynamics: EKE intensified with better model physics
- Coupled vs. uncoupled: EKE could be underestimated without air-sea interactions
- Resolution: degradation with 0.1deg ocean, but different physics

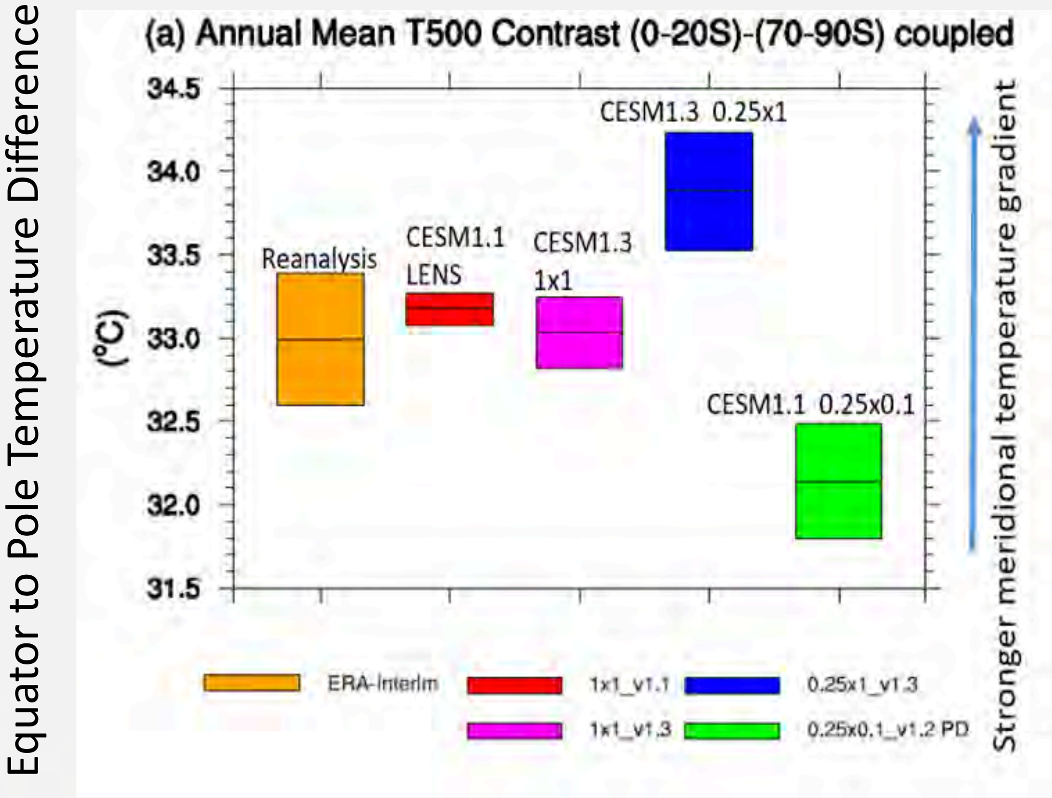
Impact of Model Physics

V1.3: more low clouds mostly in stratus regimes off west coasts and S.O.

Low Cloud Fraction



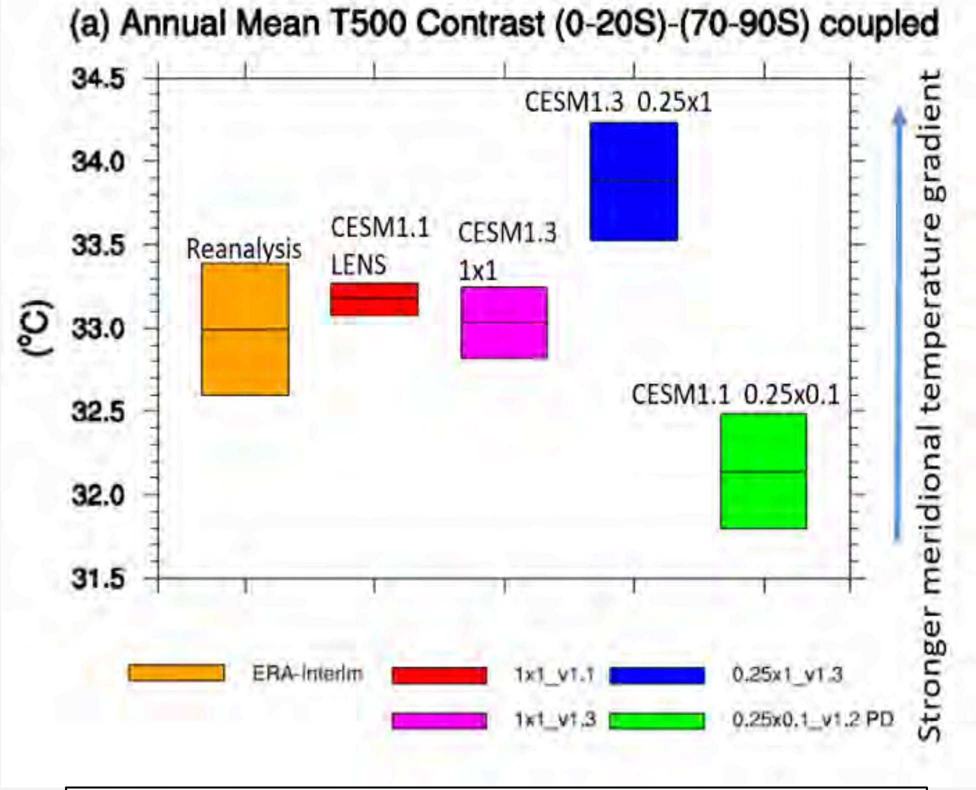
Temperature Gradient



Impact of Coupling

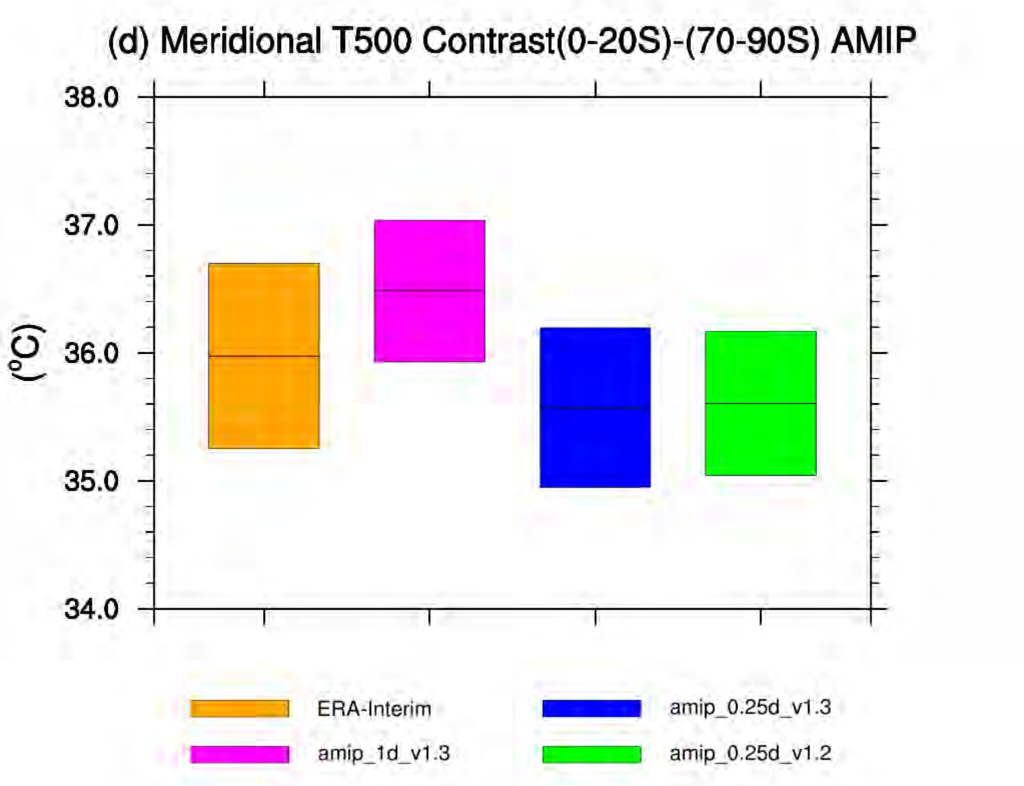
Fully Coupled

Equator to Pole Temperature Difference



Differences due to resolution and physics.

Atmosphere-only

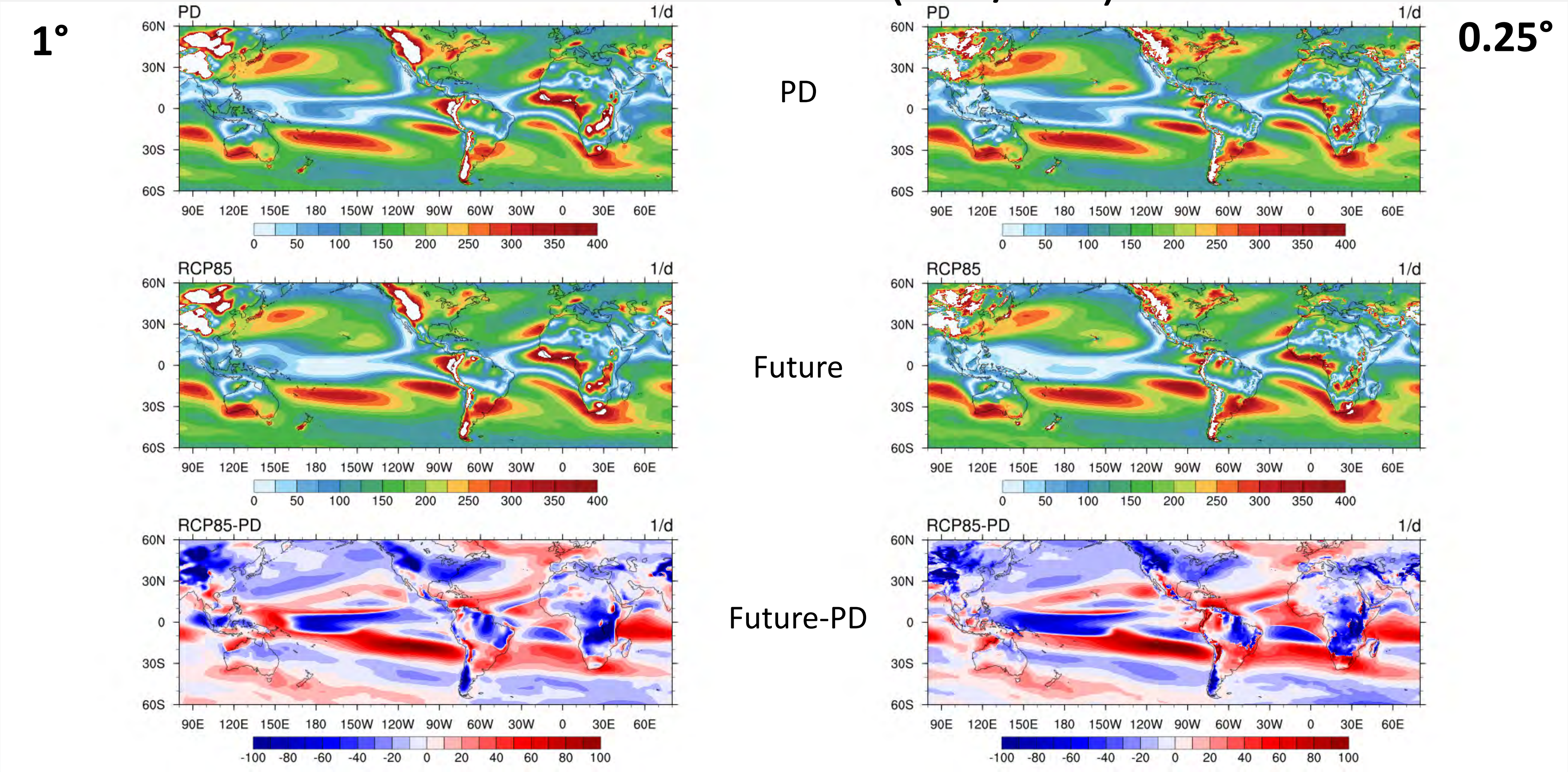


Differences due to resolution.

Summary

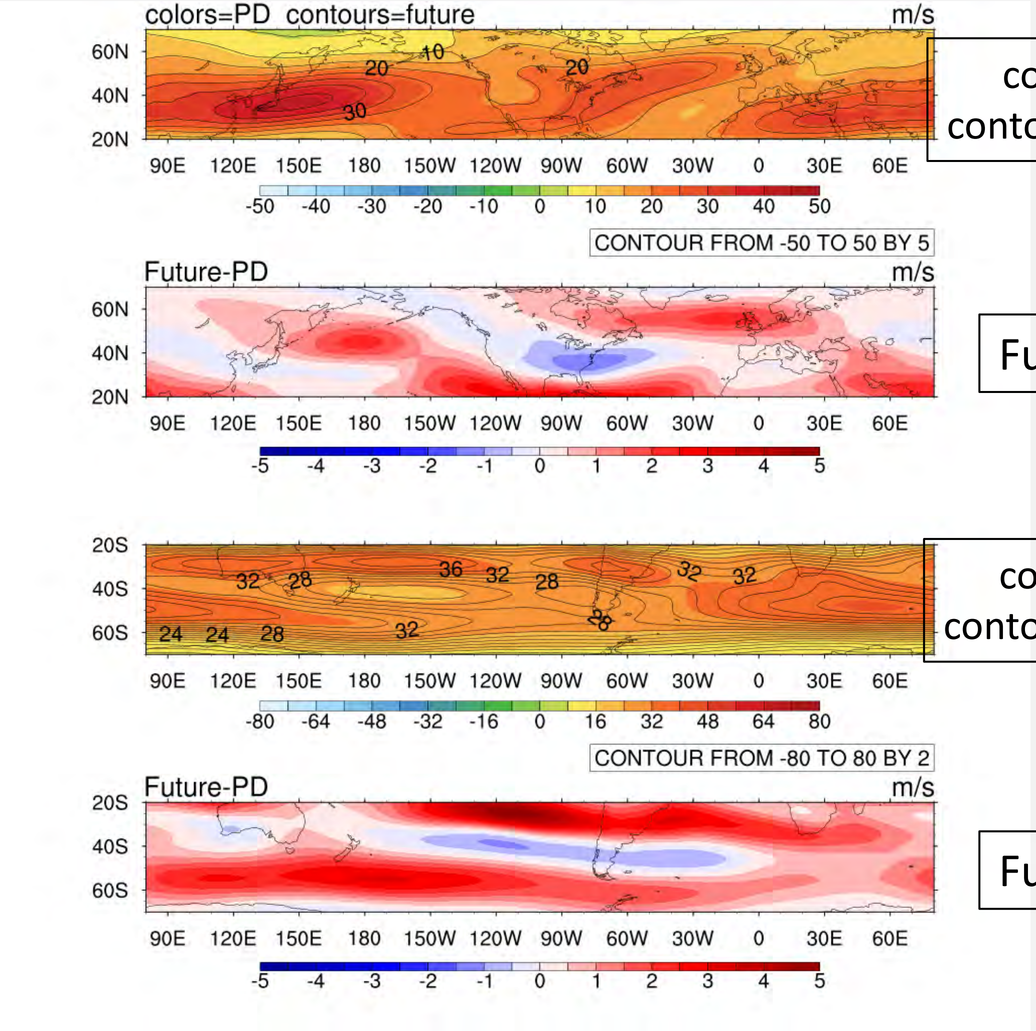
- The number of midlatitude storms are predicted to decrease in the future due to a decrease in surface temperature gradient, vertical temperature gradient, and decrease in vertical wind shear. Results not sensitive to resolution in uncoupled simulation.
- Higher resolution and better model physics do improve the representation of the Southern Hemisphere jet.
- Degradation in model physics can override the improvement due to resolution.
- The implications of this result are that simply improving resolution in atmosphere or ocean does not guarantee a better simulation of climate system dynamics. Instead, it is the combination of improved physics and improved resolution in the atmosphere that produce a better simulation of Southern Hemisphere storm tracks.

Vertical Wind Shear (du/dz) – 850mb



Zonal Wind at 200mb

1°



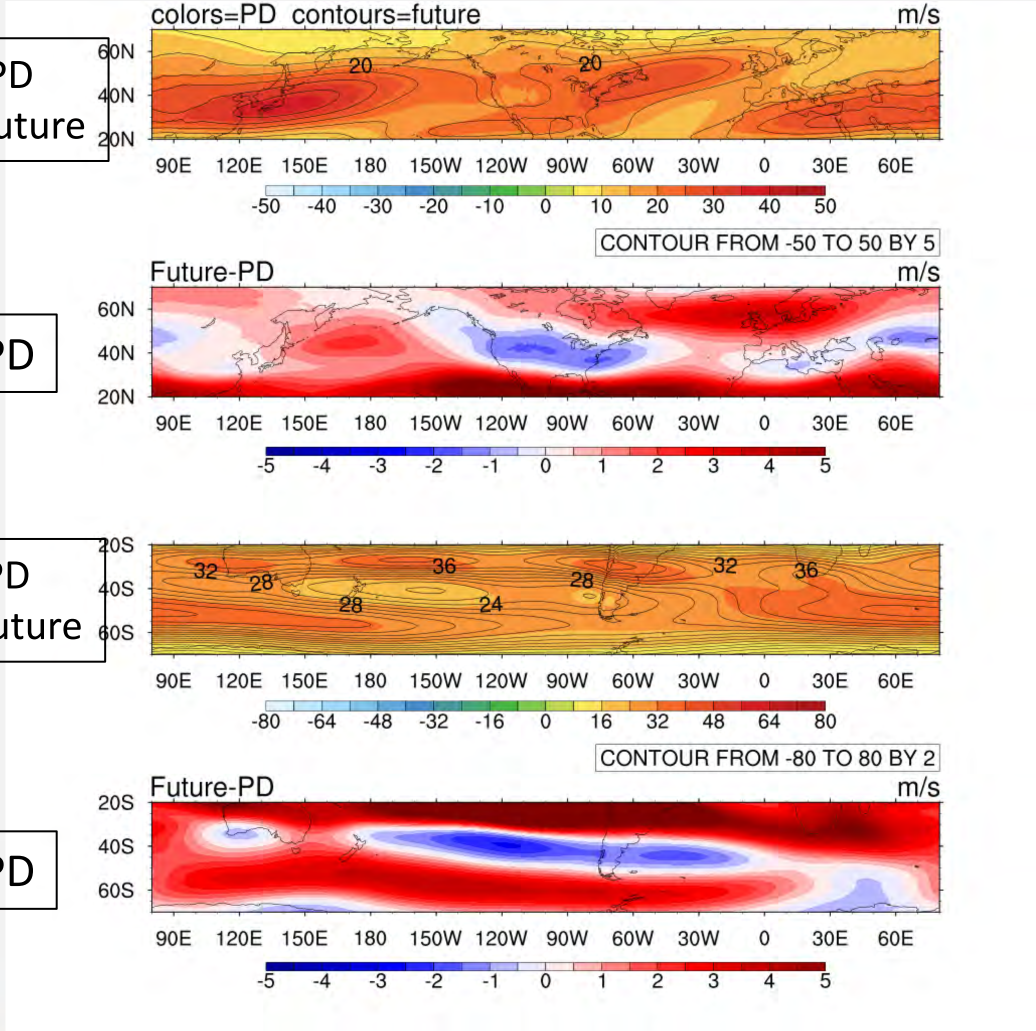
colors = PD
contours = future

Future-PD

colors = PD
contours = future

Future-PD

0.25°



Latitudinal Sea Surface Temperature