Simulations of Atmospheric Rivers using GFDL New Generation High Resolution Global Climate Model

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EGU 2020 General Assembly
Vienna, May 7, 2020

Thanks to Bin Guan for providing the AR detection code and Alex Chang for some initial analysis

Motivation

- Atmospheric rivers (ARs) cover only a small fraction of the Earth surface but play key roles in global hydrological cycle and regional weather and climate extremes.
- Accurate climate projections of high impact weather and climate extremes (e.g., flood/drought) depend on climate models' ability to simulate and predict AR phenomenon.
- The goal is to provide a systematical evaluation of the ability of GFDL new high resolution global climate model (C192AM4) in simulating the AR characteristics and response to large-scale climate variability and change.

Model and simulations

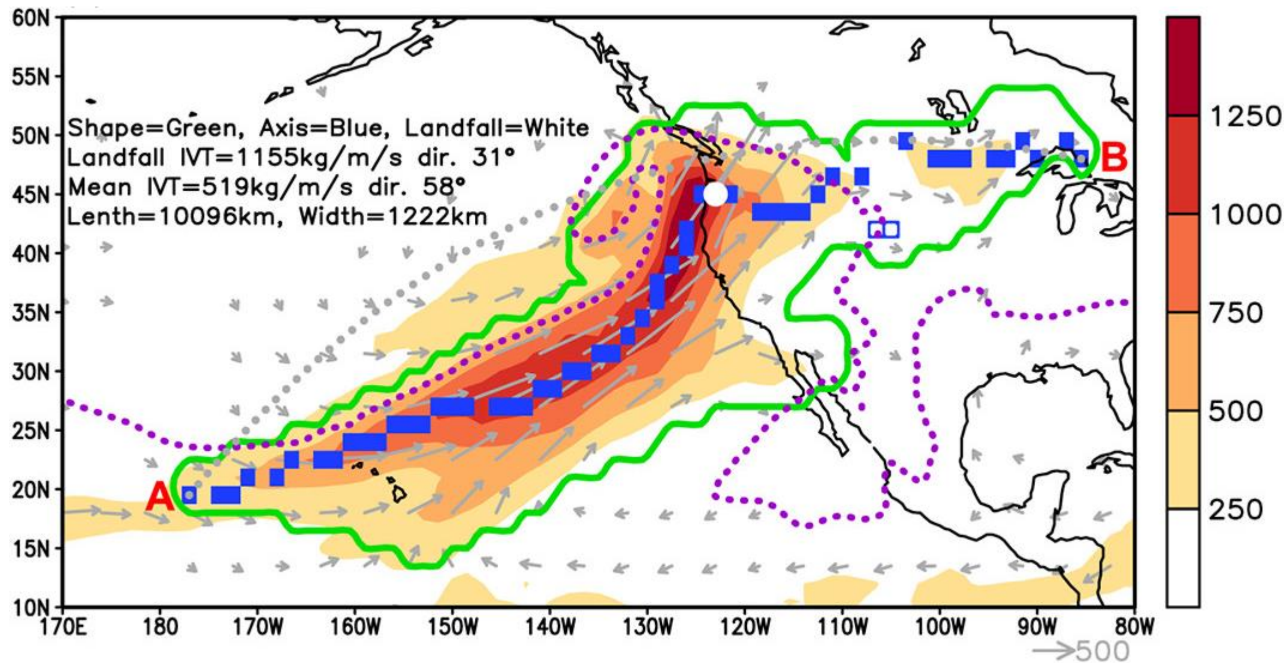
- AM4 (Zhao et.al 2018, JAMES) is the new atmospheric model used in GFDL CM4, ESM4 (both used for CMIP6) and prediction system SPEAR.
- C192AM4 is AM4 running at moderately high (~ 50km) horizontal resolution; it is used for GFDL's participation of the CMIP6 HighResMIP experiments.
- Simulations follow CMIP6 HighResMIP specifications (Haarsma et al 2016, http://collab.knmi.nl/project/highresmip/)
  - **C192AM4-PD (1979-2014)** - present-day time-varying SST/sea-ice concentration, radiative gases, solar, …
  - **C192AM4-Future (2015-2050)** - projected SST/sea-ice from CMIP5 models, SSP585 radiative gases, solar, …
  - **C192AM4-Climo** - climatological SST/sea-ice, 2010 radiation
  - **C192AM4-P4K** - as C192AM4-Climo except SST + 4K
- OBS: ERA-Interim (1979-2014, 0.75x0.75, IVTX, IVTY, PR)

AR detection method & basic measurements

AR detection uses Guan et al. (2015, JAMES)

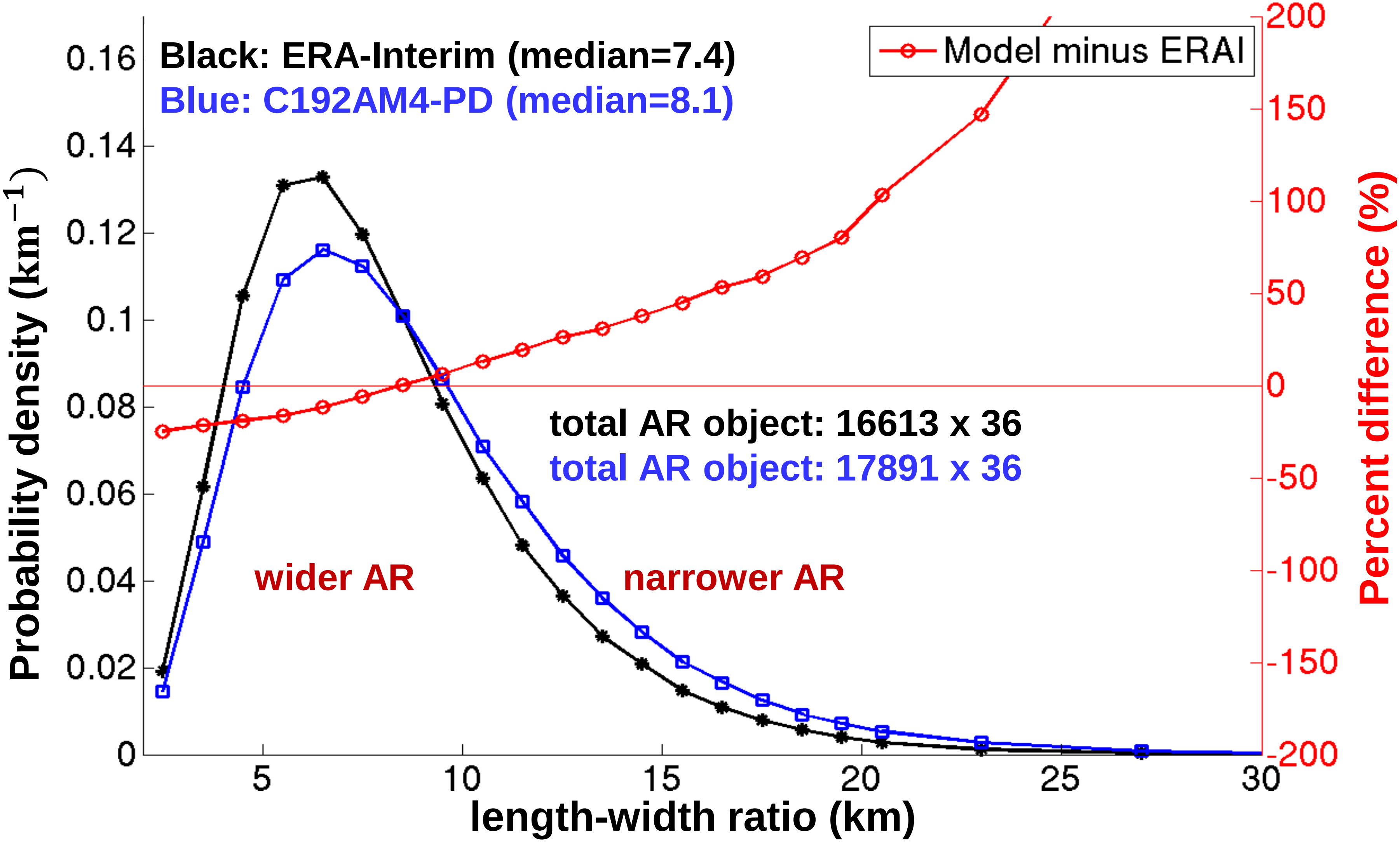
IVT (Integrated Vapor Transport) based approach with the IVT threshold=max(85th percentile IVT, 100kg/m/s)

An example of a detected AR and some basic AR measurements (Guan et al. 2015)

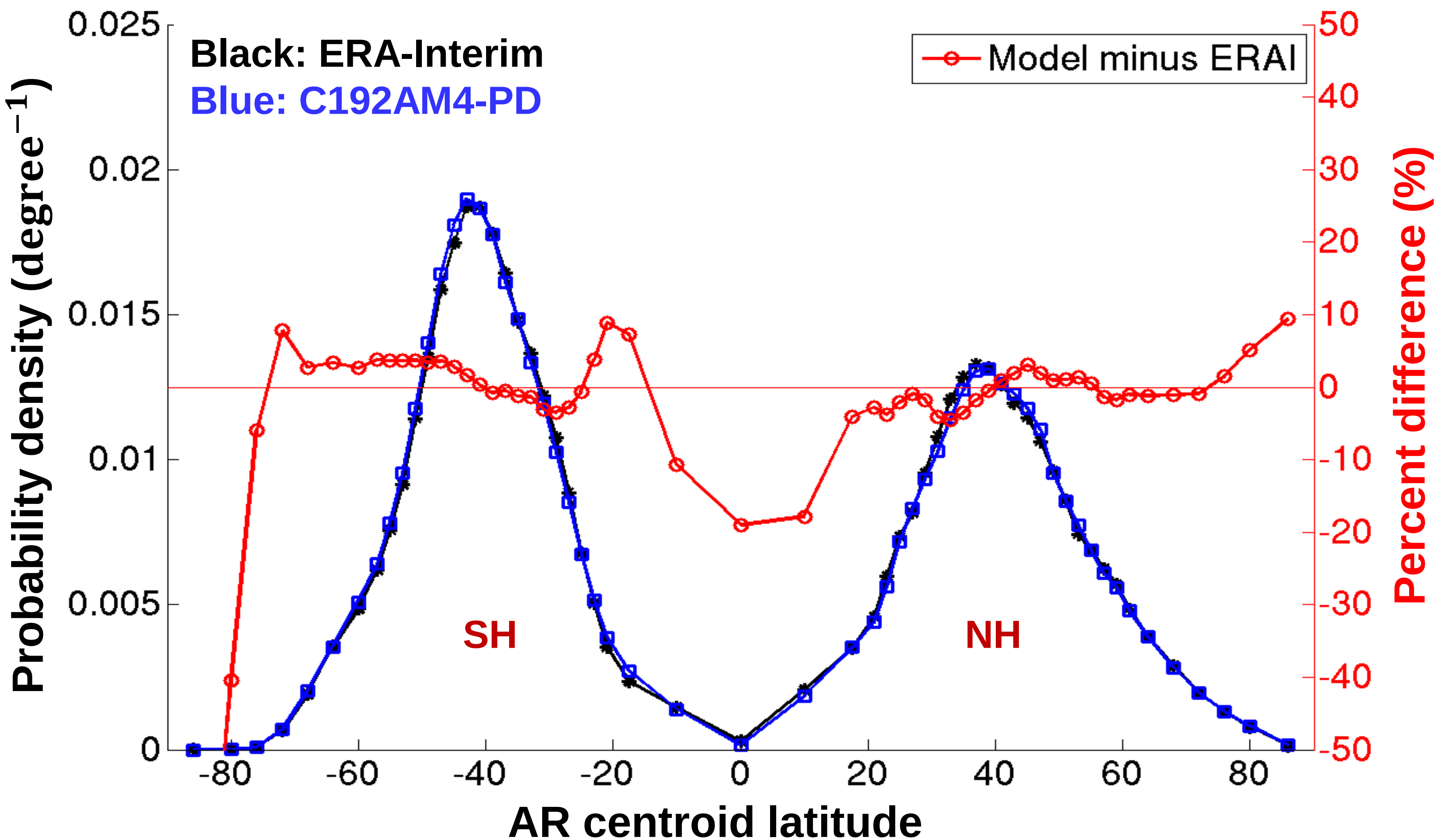


- Geometry: length, width, and length/width ratio
- Location: centroid, lowest/highest latitudes, landfall location
- Transport: zonal, meridional, and magnitude IVT=$(IVT_x^2 + IVT_y^2)^{1/2}$
- Direction: mean IVT direction and coherence of IVT direction

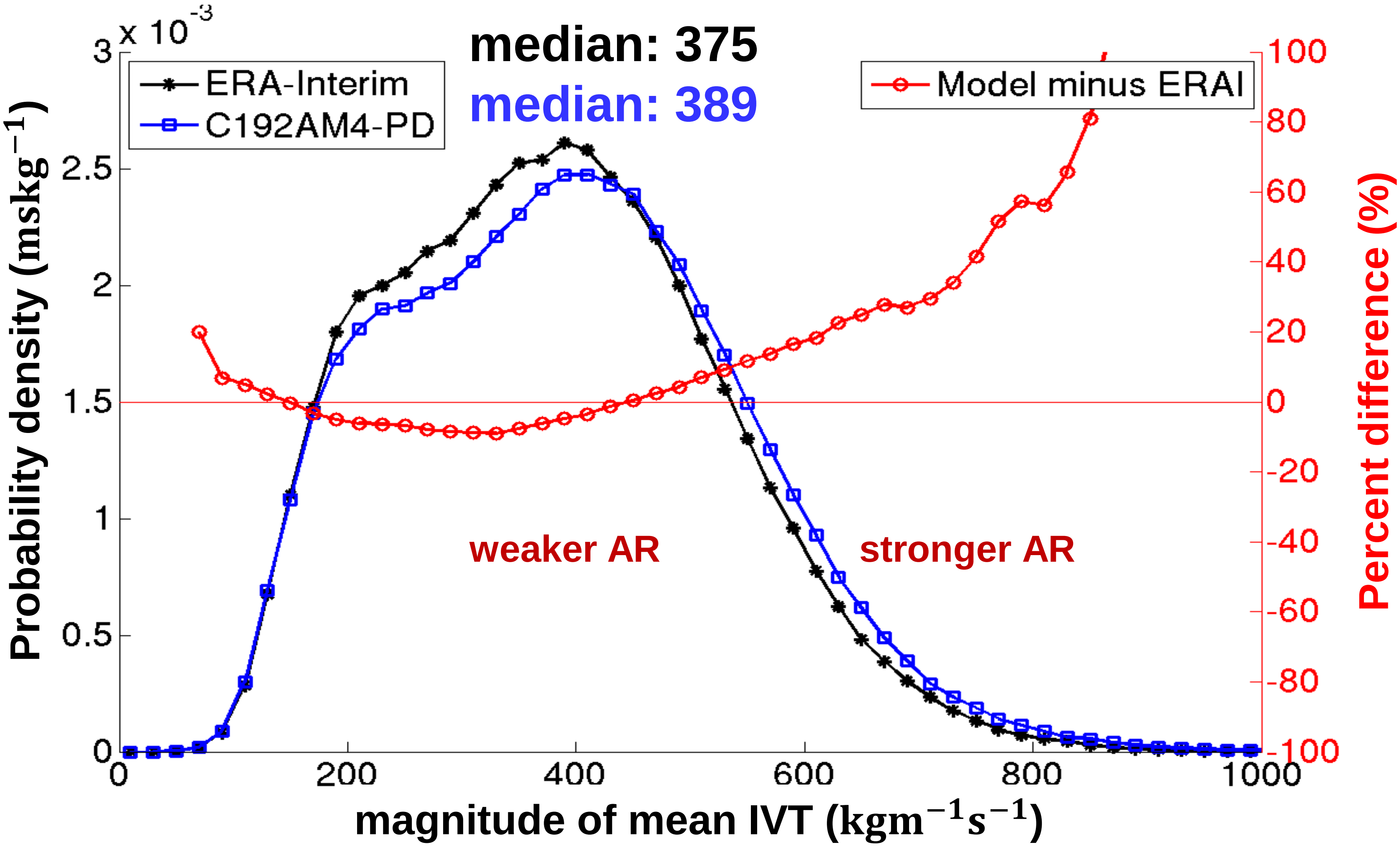
Probability distribution of AR length-width ratio



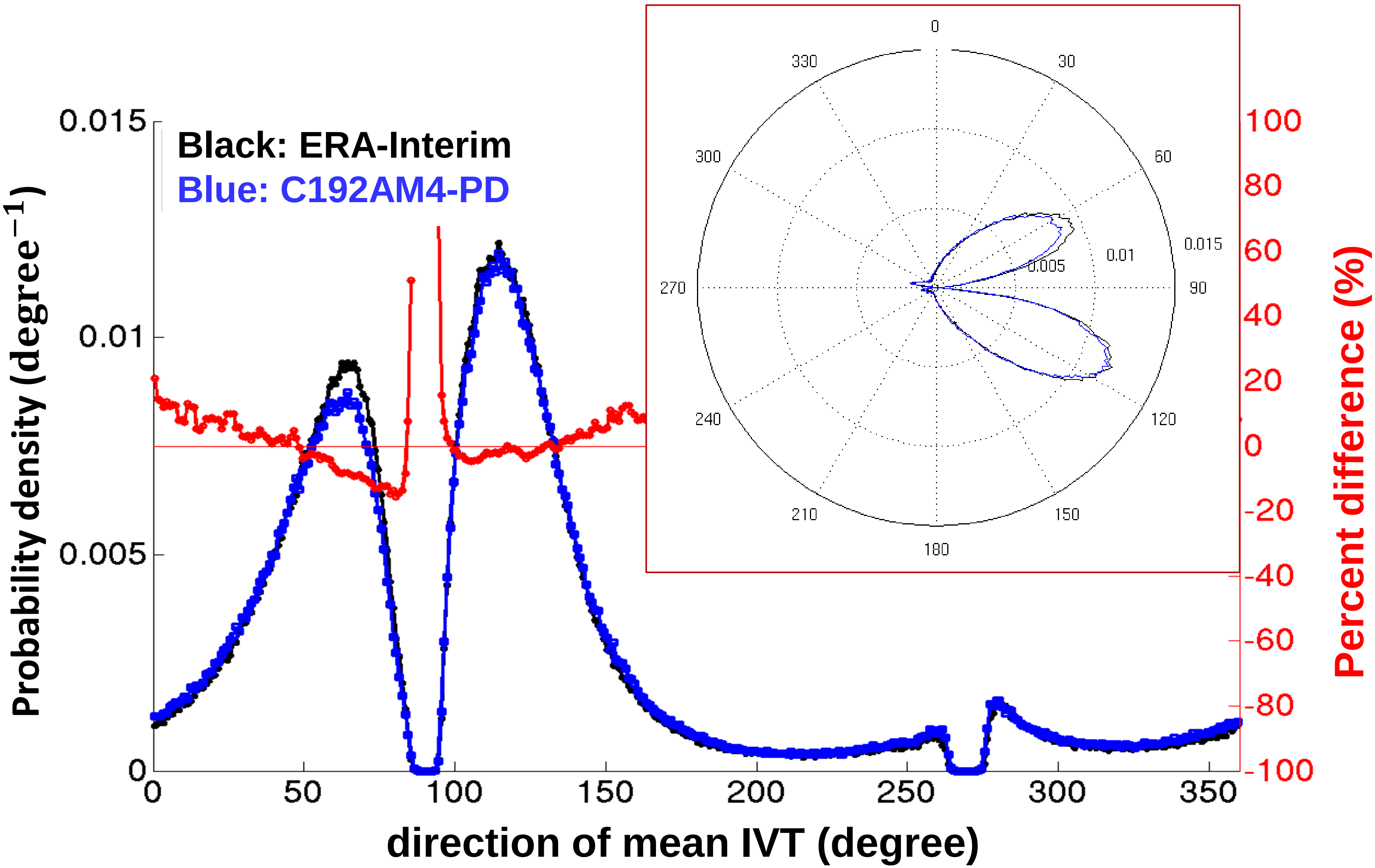
Probability distribution of AR latitudes



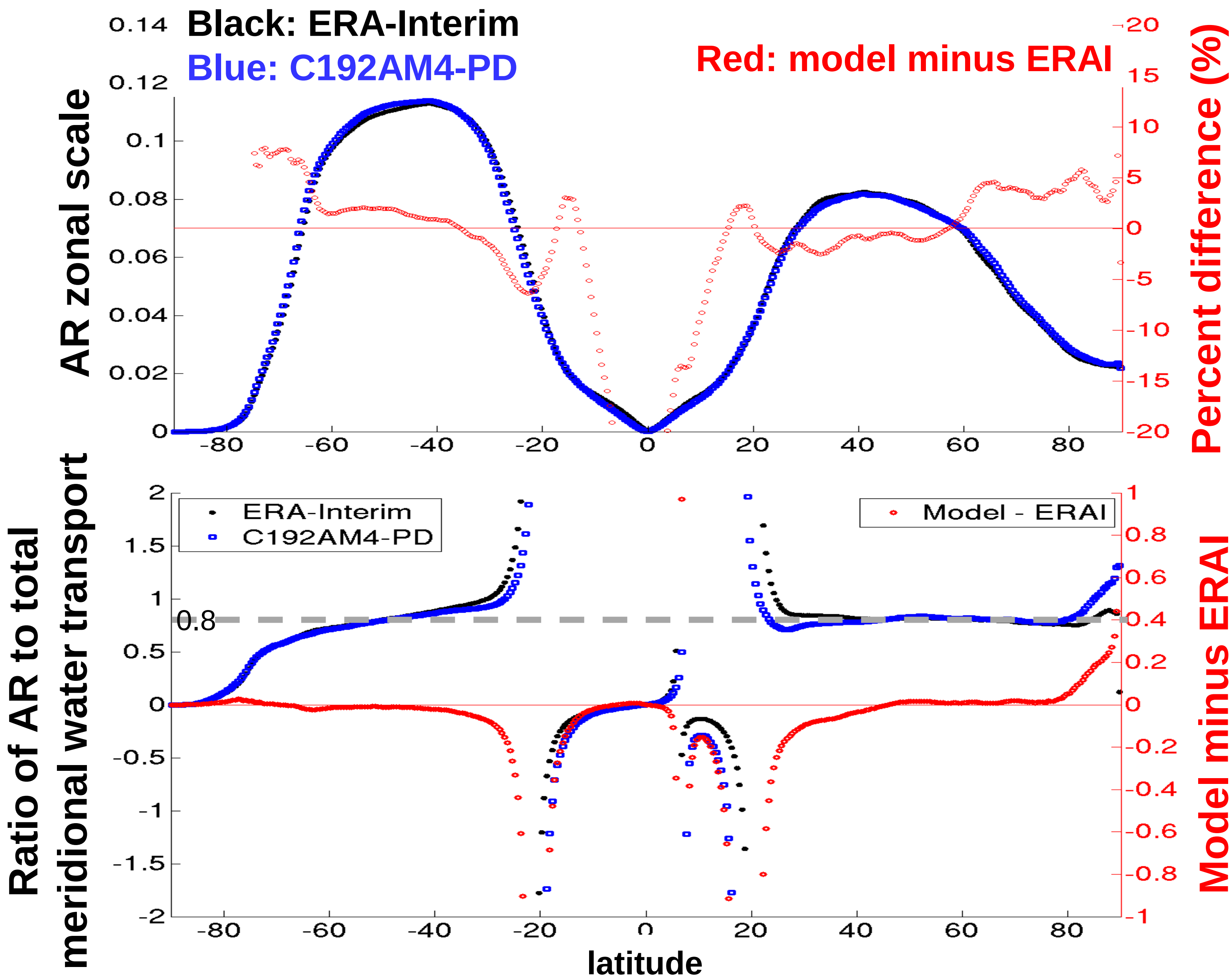
Probability distribution of AR mean IVT magnitude



Probability distribution of AR mean IVT direction

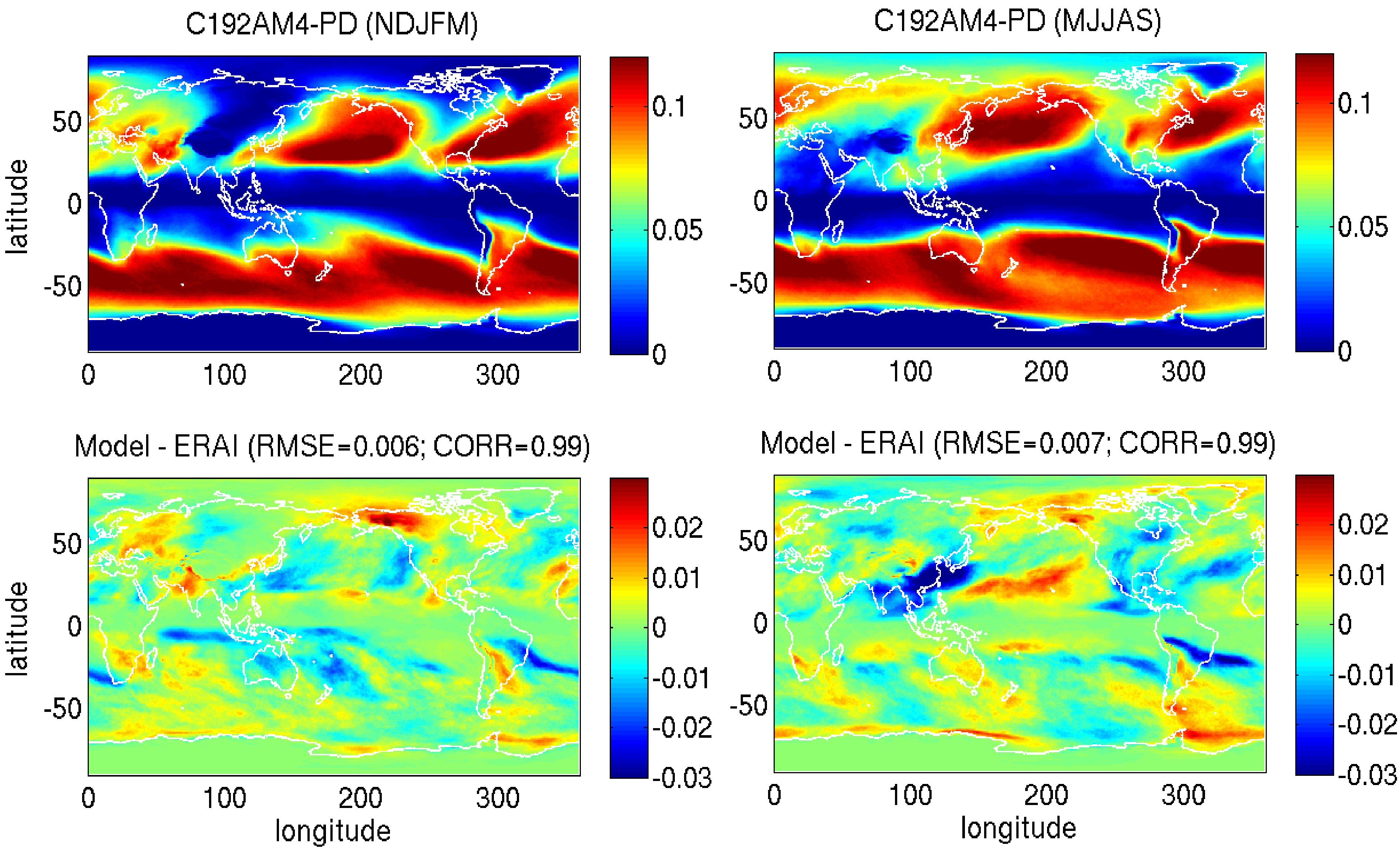


AR zonal scale & meridional water transport



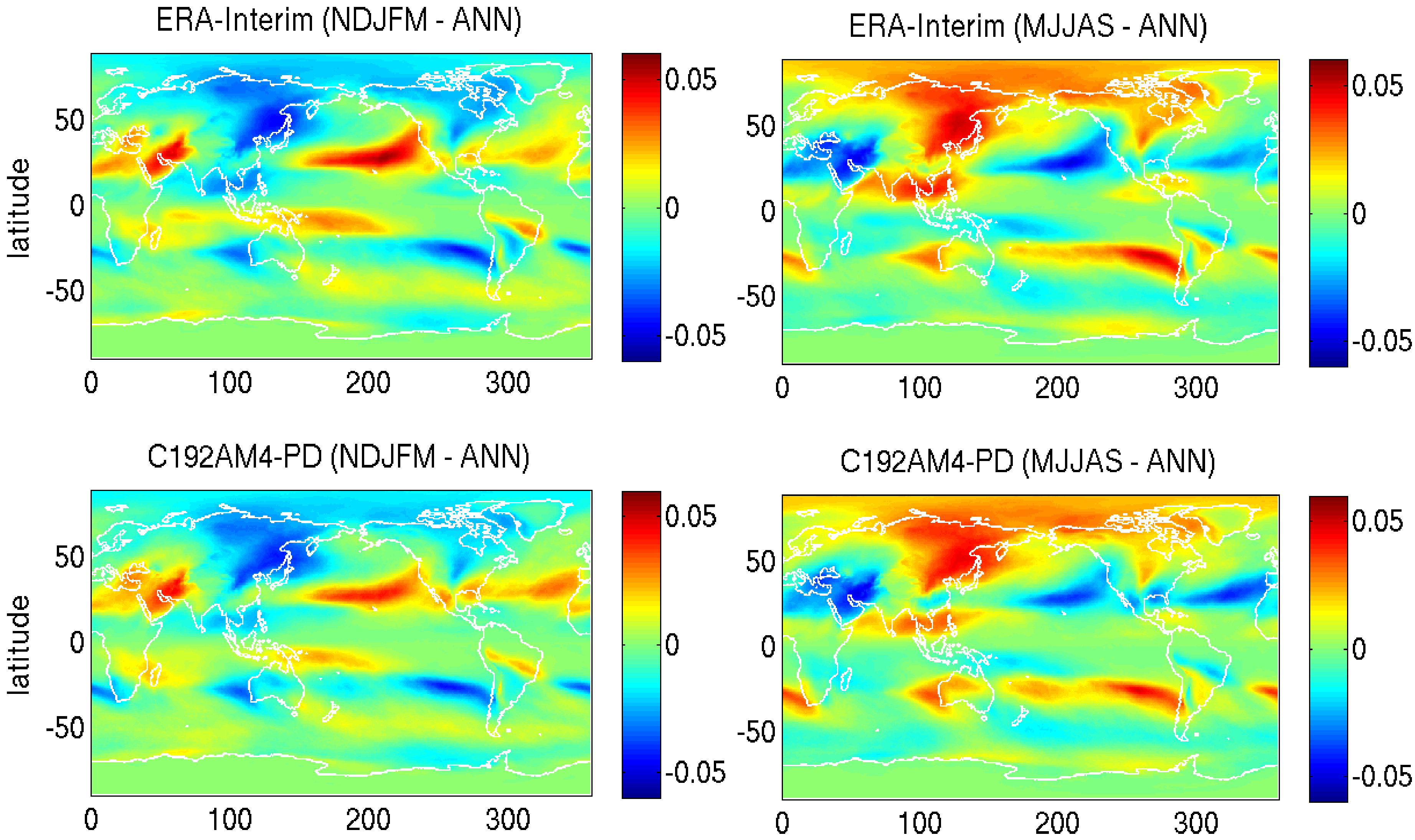
Geographical distribution of climatological AR frequency

NDJFM (November-March) | MJJAS (May-September)



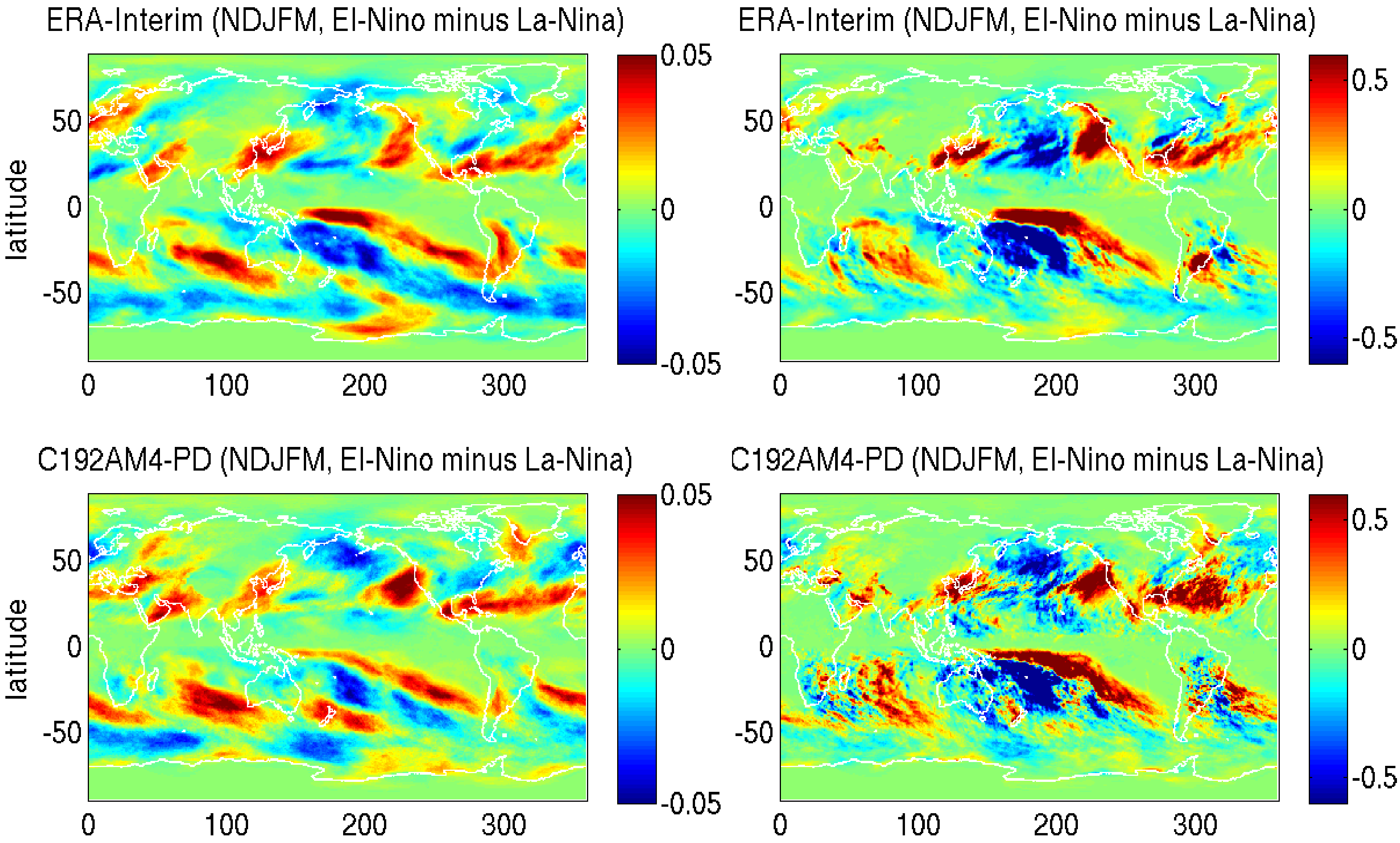
Seasonal variation of AR frequency

(NDJFM minus ANN) **(MJJAS minus ANN)**



Modulation of AR frequency & associated precipitation by El-Nino Southern Oscillation (NDJFM, El-Nino minus La-Nina)

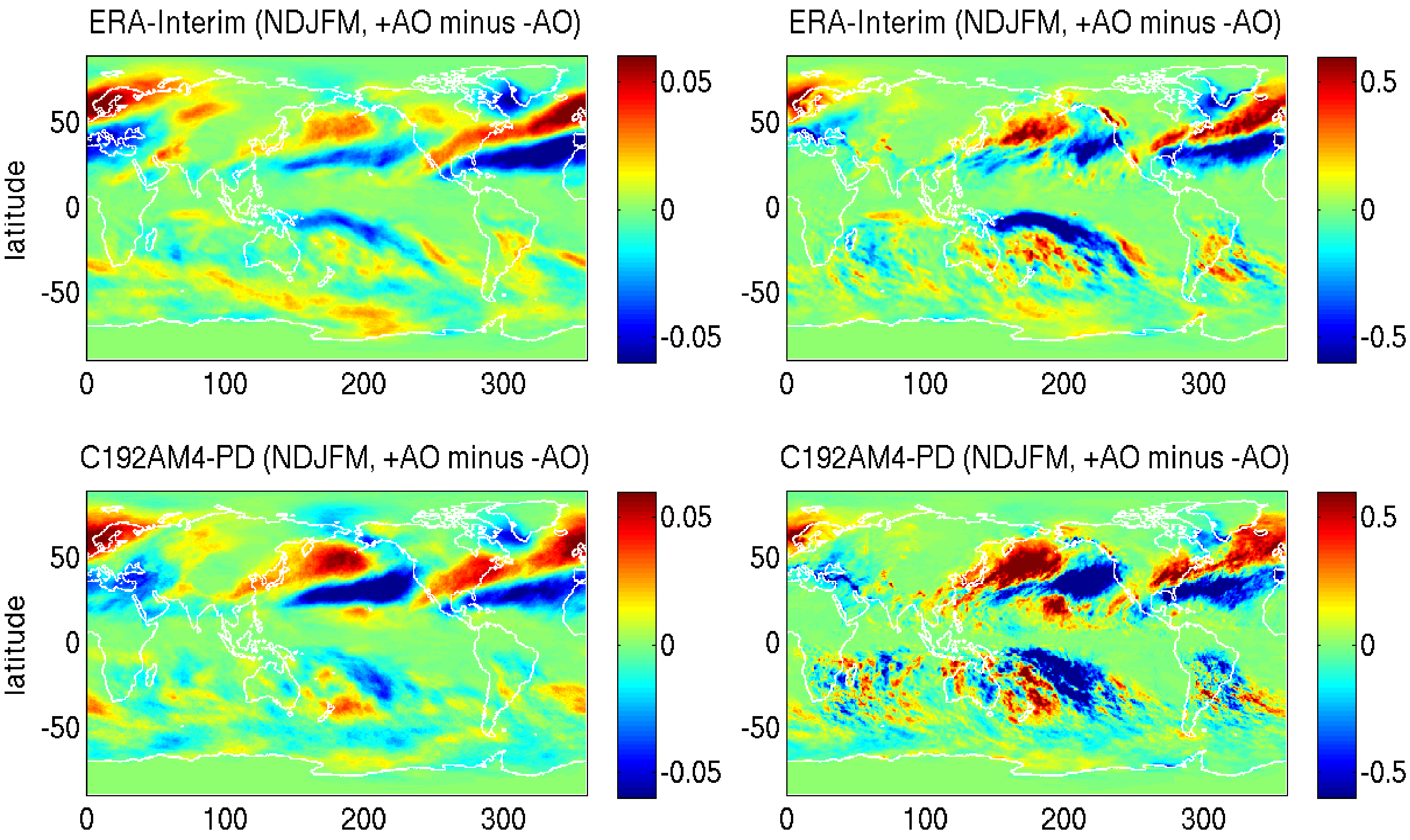
AR frequency | **AR precipitation (mm/day)**



Modulation of AR frequency & associated precipitation by the Arctic Oscillation (NDJFM, +AO minus -AO)

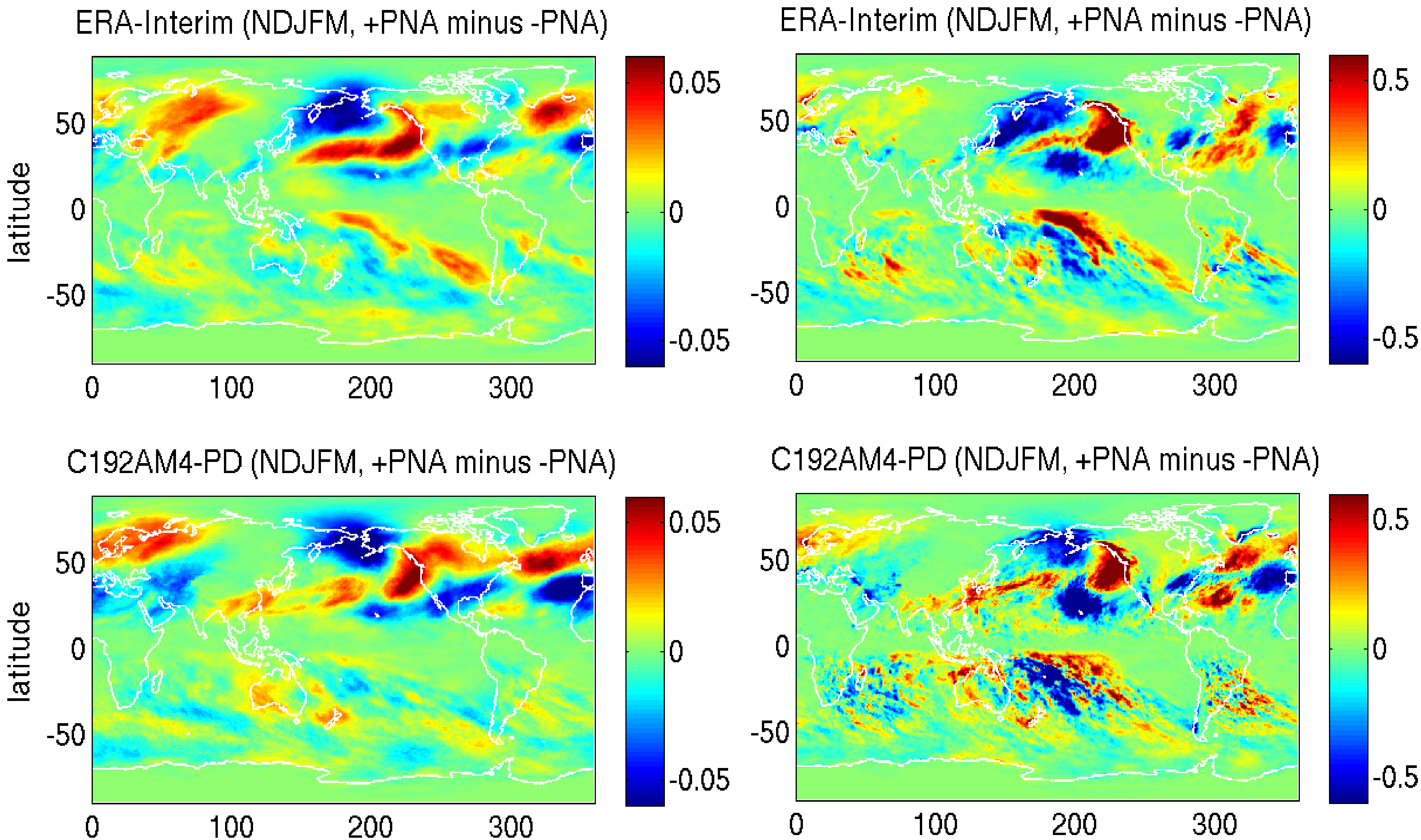
AR frequency

AR precipitation (mm/day)

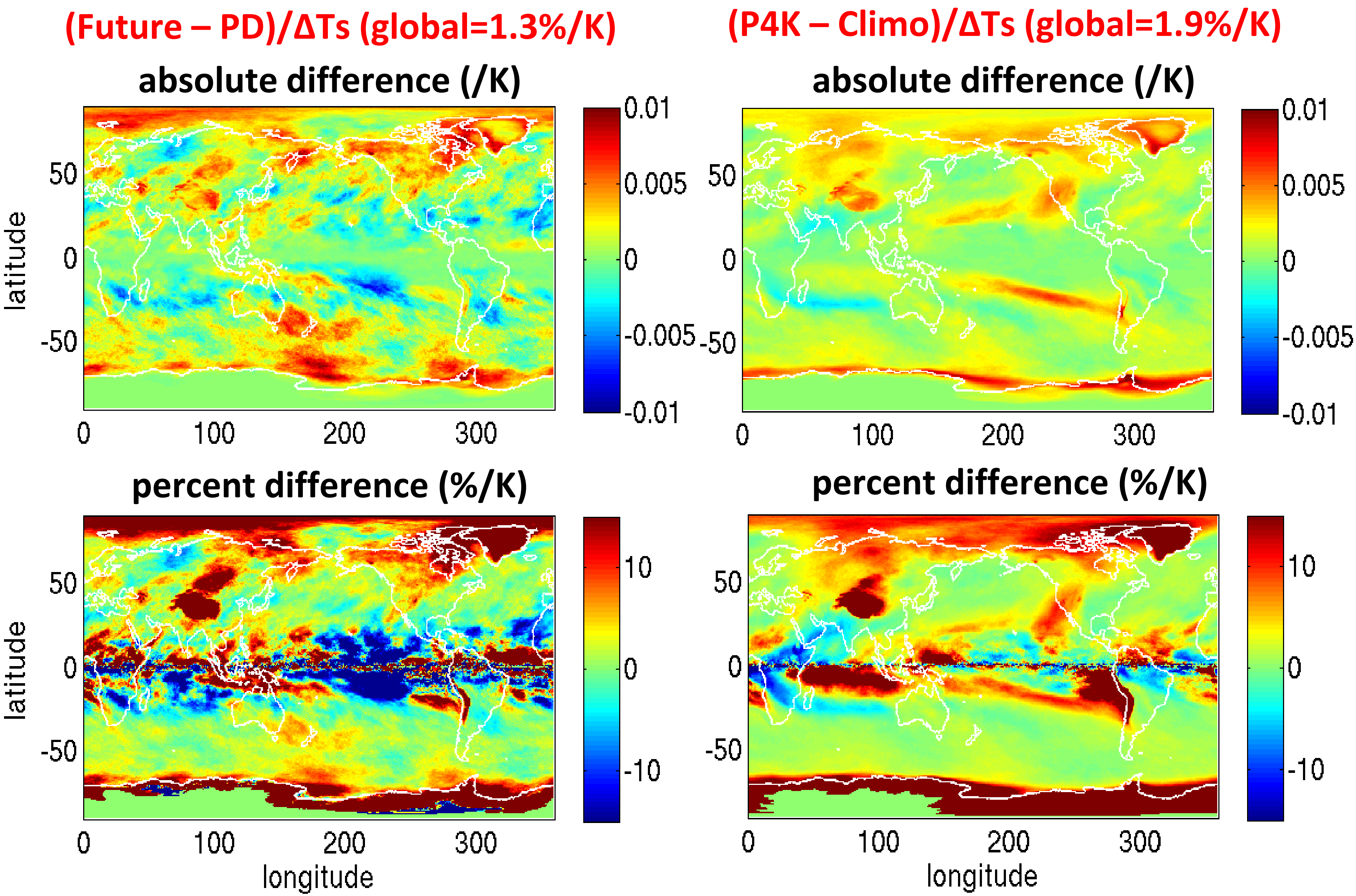


Modulation of AR frequency & associated precipitation by Pacific-North American pattern (NDJFM, +PNA minus -PNA)

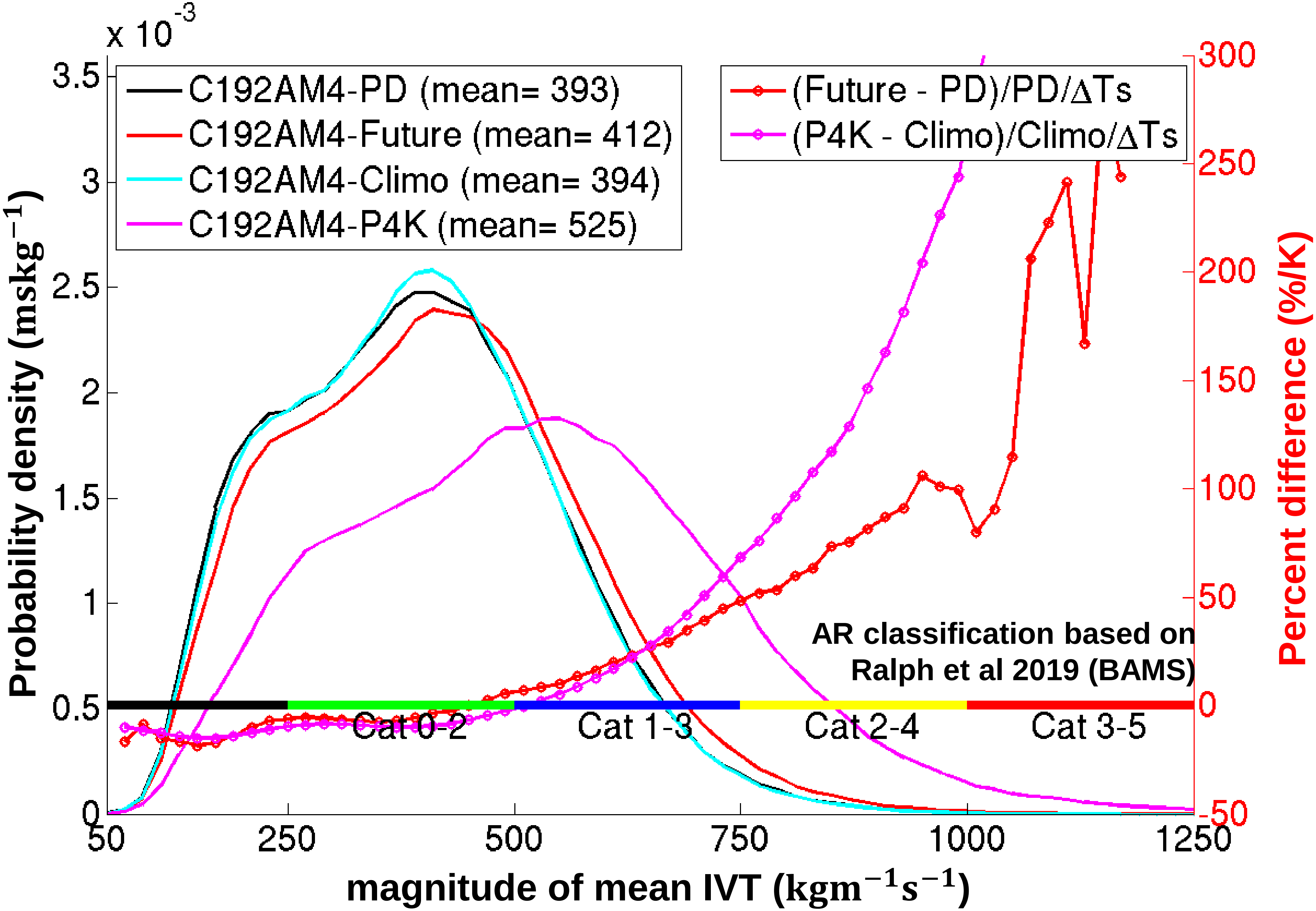
AR frequency | AR precipitation (mm/day)



Response of AR frequency to global warming

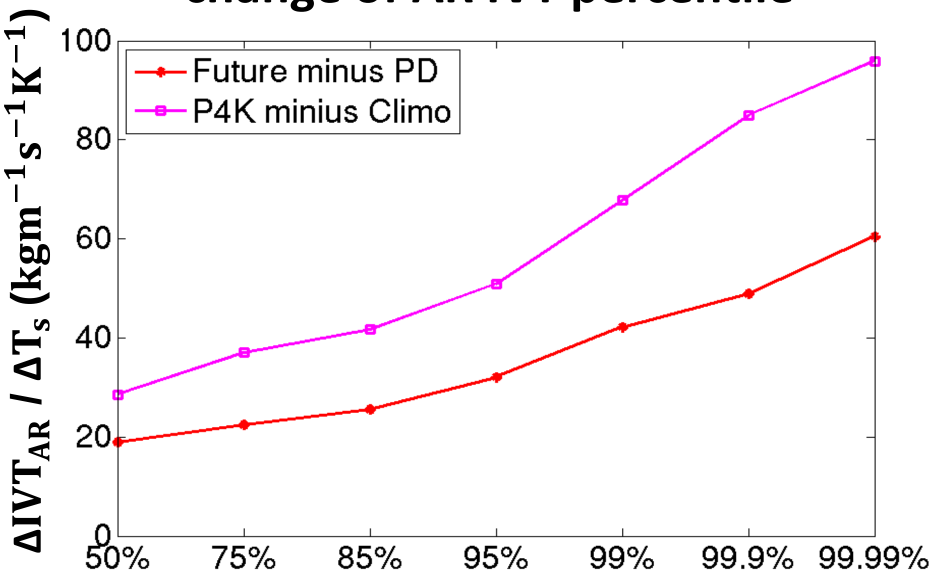


Response of AR intensity PDF to global warming

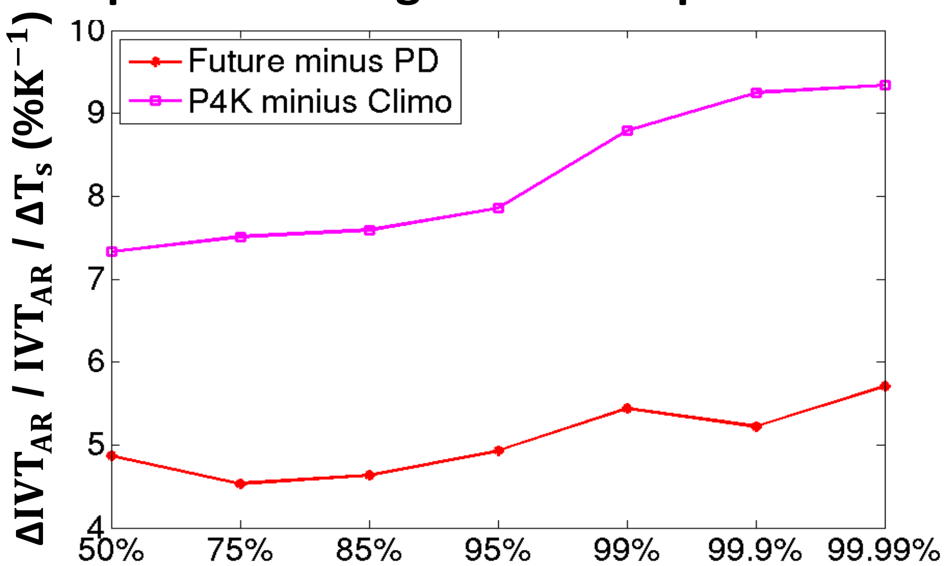


Response of AR intensity to global warming

change of AR IVT percentile

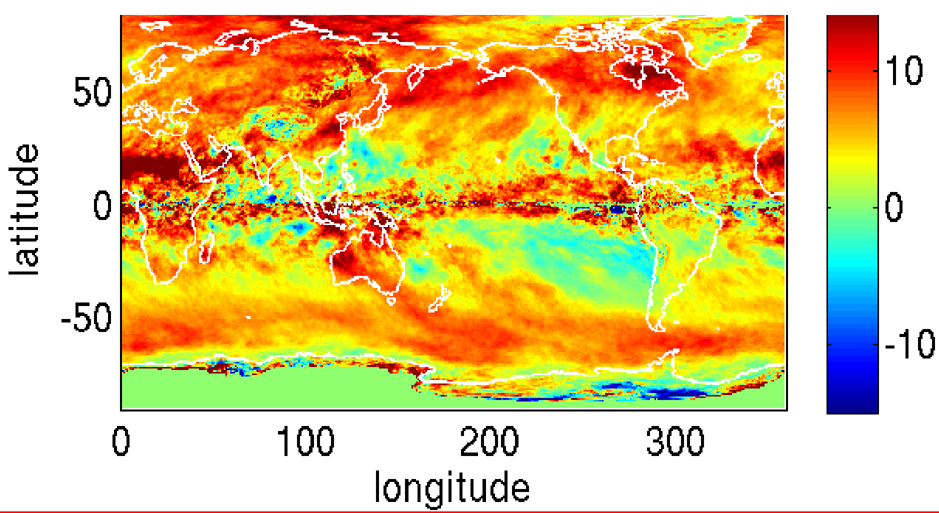


percent change of AR IVT percentile



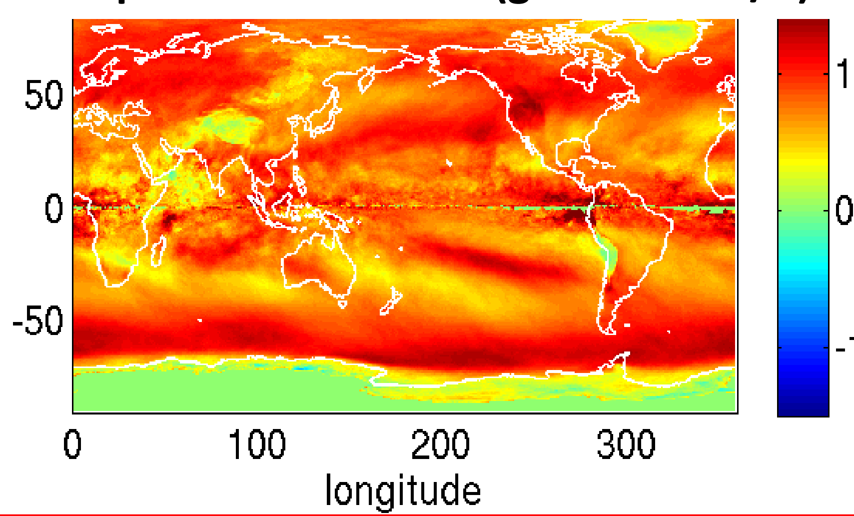
Δ IVT_{AR} (Future – PD)/PD/ΔTs

percent difference (global=5.2%/K)



Δ IVT_{AR} (P4K – Climo)/Climo/ΔTs

percent difference (global=8.0%/K)



Summary

- Compared to ERA-Interim, GFDL C192AM4 well captures many aspects of the AR characteristics including the probability distributions of AR length, width, length-width ratio, geographical location, IVT magnitude and direction with the model typically producing more narrower and stronger ARs.
- C192AM4 also reproduces well the geographical distribution of AR frequency and their variability in response to large-scale circulation patterns such as the El-Nino Southern Oscillation, Arctic Oscillation, and Pacific North American pattern despite with significant biases at regional scales.
- C192AM4 produces only a modest increase (1-2%/K) of global total AR frequency in response to global warming. However, there is a larger increase of stronger ARs with the Cat 3-5 ARs increased by roughly 100-300%/K. The global mean AR intensity increases by 5-8%/K, roughly following Clausius-Clapeyron scaling of water vapor.