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=$\max(85^{\text{th}}\ \text{percentile IVT}, \ 100\text{kg/m/s})$

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

- Black: ERA-Interim (median=7.4)
- Blue: C192AM4-PD (median=8.1)

Percent difference (%)

Probability density (km\(^{-1}\))

length-width ratio (km)

Total AR objects:
- ERA: 16613 x 36
- C192AM4-PD: 17891 x 36

Wider AR
Narrower AR

Model minus ERAI
Probability distribution of AR latitudes

Black: ERA-Interim
Blue: C192AM4-PD

- SH
- NH

Probability density (degree$^{-1}$)

Percent difference (%)
Probability distribution of AR mean IVT magnitude

- Median: 375
- Median: 389

- Weaker AR
- Stronger AR

- ERA-Interim
- C192AM4-PD

- Probability density (mskg^{-1})
- Percent difference (%)
Probability distribution of AR mean IVT direction

Black: ERA-Interim
Blue: C192AM4-PD
AR zonal scale & meridional water transport

Black: ERA-Interim
Blue: C192AM4-PD
Red: model minus ERAI

Ratio of AR to total meridional water transport

Percent difference (%)
Geographical distribution of climatological AR frequency

**NDJFM (November-March)**

C192AM4-PD (NDJFM)

**MJJAS (May-September)**

C192AM4-PD (MJJAS)

Model - ERAI (RMSE=0.006; CORR=0.99)

Model - ERAI (RMSE=0.007; CORR=0.99)
Seasonal variation of AR frequency

(NDJFM minus ANN)
ERA-Interim (NDJFM - ANN)

(MJJAS minus ANN)
ERA-Interim (MJJAS - ANN)

C192AM4-PD (NDJFM - ANN)

C192AM4-PD (MJJAS - ANN)
Modulation of AR frequency & associated precipitation by El-Nino Southern Oscillation (NDJFM, El-Nino minus La-Nina)

AR frequency

ERA-Interim (NDJFM, El-Nino minus La-Nina)

AR precipitation (mm/day)

ERA-Interim (NDJFM, El-Nino minus La-Nina)

C192AM4-PD (NDJFM, El-Nino minus La-Nina)

C192AM4-PD (NDJFM, El-Nino minus La-Nina)
Modulation of AR frequency & associated precipitation by the Arctic Oscillation (NDJFM, +AO minus -AO)

AR frequency

ERA-Interim (NDJFM, +AO minus -AO)

C192AM4-PD (NDJFM, +AO minus -AO)

AR precipitation (mm/day)

ERA-Interim (NDJFM, +AO minus -AO)

C192AM4-PD (NDJFM, +AO minus -AO)
Modulation of AR frequency & associated precipitation by Pacific-North American pattern (NDJFM, +PNA minus -PNA)

AR frequency

ERA-Interim (NDJFM, +PNA minus -PNA)

C192AM4-PD (NDJFM, +PNA minus -PNA)

AR precipitation (mm/day)

ERA-Interim (NDJFM, +PNA minus -PNA)

C192AM4-PD (NDJFM, +PNA minus -PNA)
Response of AR frequency to global warming

(Future – PD)/ΔTs (global=1.3%/K)

(P4K – Climo)/ΔTs (global=1.9%/K)
Response of AR intensity PDF to global warming magnitude of mean IVT ($\text{kg m}^{-1} \text{s}^{-1}$)

Probability density ($\text{ms kg}^{-1}$)

Percent difference (%/K)

AR classification based on Ralph et al 2019 (BAMS)

- C192AM4-PD (mean = 393)
- C192AM4-Future (mean = 412)
- C192AM4-Climo (mean = 394)
- C192AM4-P4K (mean = 525)
Response of AR intensity to global warming

\[ \Delta IVT_{AR} \] (Future – PD)/PD/\( \Delta T_s \)
percent difference (global=5.2%/K)

\[ \Delta IVT_{AR} \] (P4K – Climo)/Climo/\( \Delta T_s \)
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.