ICON-A, the atmospheric component of the ICON Earth System Model

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Related manuscripts

- ICON-A, the atmospheric component of the ICON Earth System Model
  - Part I: Model description
    M. A. Giorgetta, R. Brokopf, T. Crueger, M. Esch, S. Fiedler, J. Helmert, C. Hohenegger, L. Kornblueh, M. Köhler, E. Manzini, T. Mauritsen, C. Nam, S. Rast, C. Reick, D. Reinert, M. Sakradzija, H. Schmidt, R. Schnur, L. Silvers, H. Wan, G. Zängl, and B. Stevens
  - Part II: Model evaluation
    T. Crueger, M. A. Giorgetta, R. Brokopf, M. Esch, S. Fiedler, C. Hohenegger, L. Kornblueh, T. Mauritsen, C. Nam, A. K. Naumann, K. Peters, S. Rast, E. Roeckner, M. Sakradzija, H. Schmidt, J. Vial, R. Vogel, B. Stevens
- Under review in Journal of Advances in Modeling Earth Systems (JAMES)

Contents

- The ICON-A model in a nutshell
- Grids: horizontal and vertical
- Dynamics – physics coupling
- Tuning of ICON-A
- Evaluation of ICON-A
- Summary
- Outlook to ICON-ESM

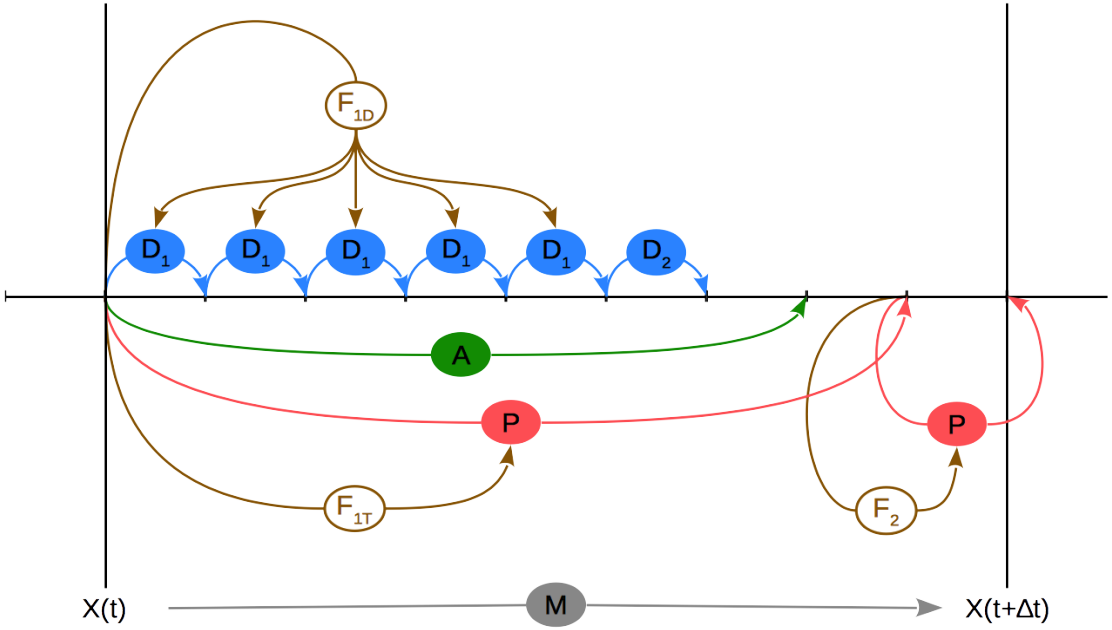
ICON-A in a nutshell - Requirements

- Global atmosphere for mostly long simulations
  - Atmosphere only: AMIP, aqua planet, rad.-conv. equilibrium
  - Climate simulations: piControl, historical, abrupt4xCO2, ...
- Closed water cycle
- Realistic energy budget, especially at the top of the atmosphere
- Acceptable biases of multi-year/decadal climate
  - AMIP experiment ↔ ERA-interim + selected observations
- “Workhorse”: to be used for many and inexpensive simulations
- And sometimes also at much coarser or higher resolutions
  - Climate feedback studies from $\Delta x = 2560$ km to $\Delta x = 5$ km

ICON-A in a nutshell – construction

- ICON dynamics and tracer advection
- Physics adopted from ECHAM6.3
  - Radiation: Pincus and Stevens (2013) PSrad ≈ RRTMG, used with McICA, but without McSI
  - Vertical diffusion: Mauritsen et al. (2007) Total turbulent energy scheme, implicitly coupling to land
  - Land surface: JSBACH4 Refactored JSBACH3, 5 layer soil, “lite” version is used
  - Convection: Tiedtke (1987), Nordeng (1994) Mass flux, single plume, shallow, deep or mid-level
  - Cloud microph..: Lohmann and Roeckner (1996) q, clw, cli (single moments), diagnostic rain and snow
  - Cloud cover: Sundqvist et al. (1989) Profile of critical relative humidity
  - SSO drag: Lott (1999) Blocking, gravity wave drag
  - Atm. gravity waves: Hines (1997) Vertical wavenumber spectra in 8 azimuths, launch level in mid troposphere, globally uniform source strength
  - Methane oxidation and water vapor photolysis:: IFS documentation Cy36r1, relaxation scheme
- Dynamics – physics coupling: “Similar but different” to NWP

Dynamics physics splitting in ICON



$$M = P(F_2) \circ \left(P(F_{1T}) + A + D_2 \circ D_1^n(F_{1D}) \right)$$

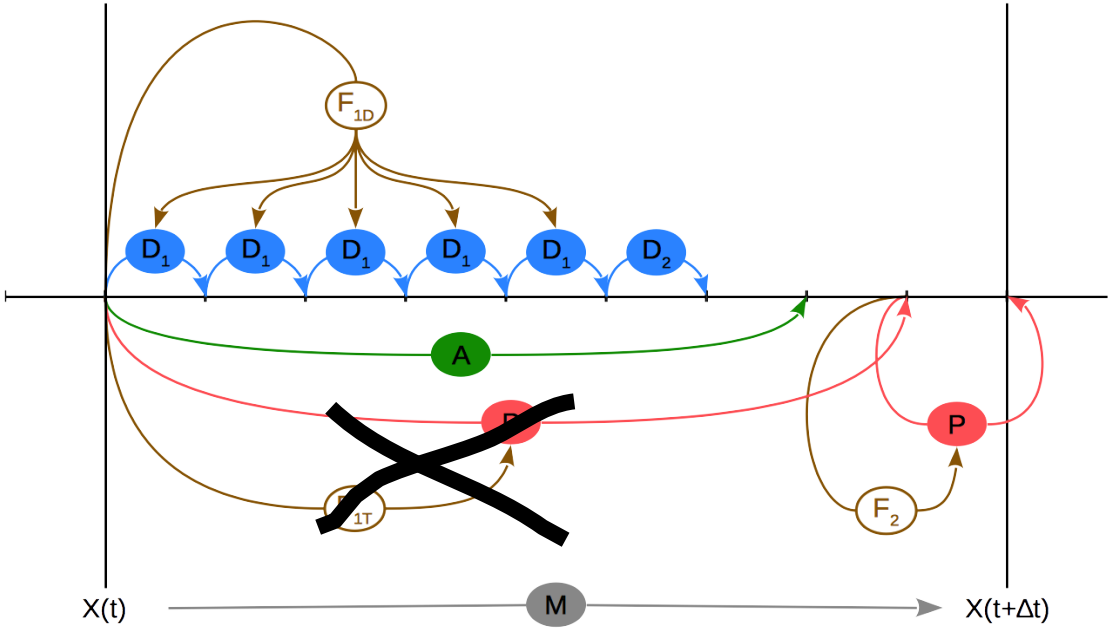
Updating operators

- Dynamics: D_1 and D_2
- Tracer advection A
- Physics

Forcing

- F_{1D}: “slow” physics on dynamics
- F_{1T}: “slow” physics on tracers
- F_2: “fast” physics

Dynamics physics splitting in ICON-A



$$M = P(F_2) \circ \left(D_1^n(F_{1D}) + A + D_2 \circ D_1^n(F_{1D}) \right)$$

Updating operators

- Dynamics: D_1 and D_2
- Tracer advection A
- Physics

Forcing

- F_{1D}: “slow” physics on dynamics
- F_{1T}: “slow” physics on tracers
- F_2: “fast” physics

Horizontal grid

- **R2B4:** 5-fold refinement of the spherical icosahedron
- 20‘480 spherical triangles
- 30‘720 great circle edges
- 10‘242 vertices,
  12 with 5 triangles, at N/S and ~26°N/S
  All others with 6 triangles
- 96 rows around the N-S axis
- Tropical rows have 320 triangles
- Mean area $\overline{a}$ = 24907 km²
- Mean res. $\overline{dx}$ = SQRT($\overline{a}$) = 157 km
- Spring dynamics (Tomita et al., 2001) for more equal edge lengths.

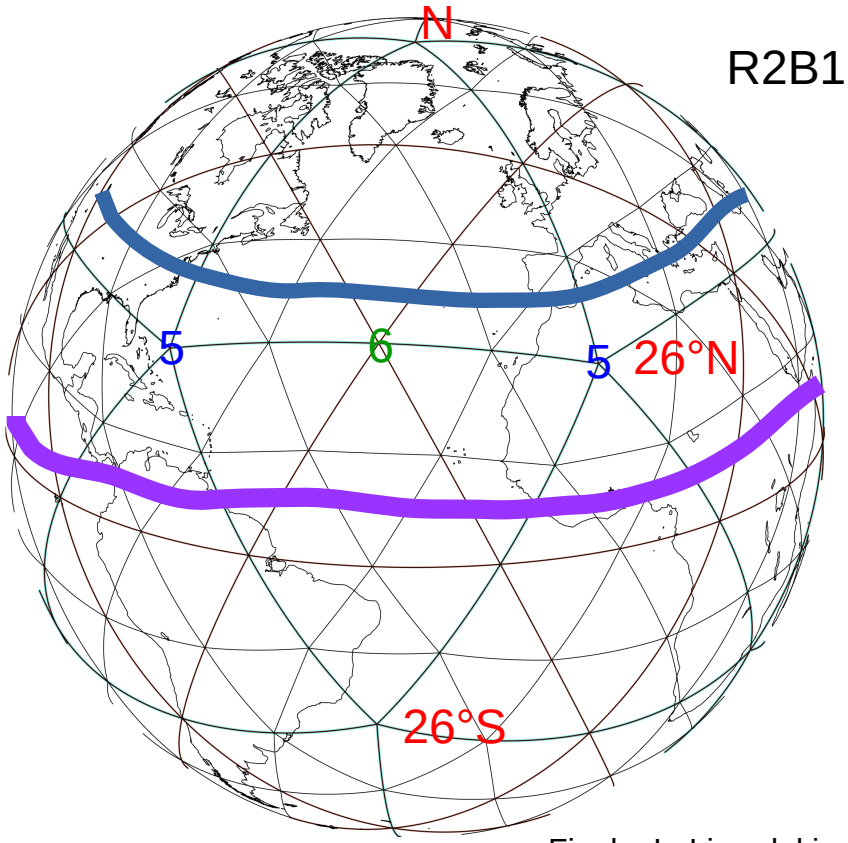
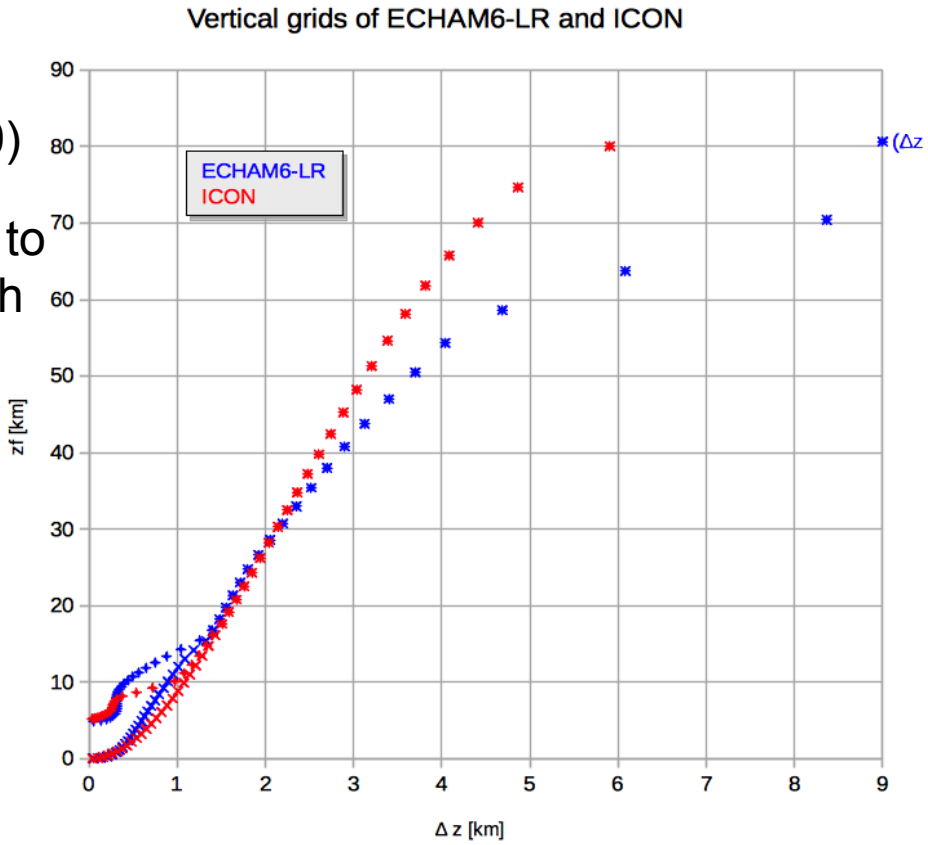


Fig. by L. Linardakis

Vertical grid: 47 levels to 80 km

- Generalized smooth-level vertical coordinate (Leuenberger et al., 2010)
- Smooth structure of terrain is visible to higher heights than small scale rough structure.
- $z_h(\lambda,\varphi,k) = A(k) + B(\lambda,\varphi,k)\cdot z_s(\lambda,\varphi)$
  $z_f(\lambda,\varphi,k) = (z_h(\lambda,\varphi,k)+z_h(\lambda,\varphi,k+1))/2$
- B = 1 at surface, B = 0 for z > 16 km
- ECHAM: Hybrid p-sigma:
  $p_h(\lambda,\varphi,k) = a(k) + b(k)\cdot p_s(\lambda,\varphi)$



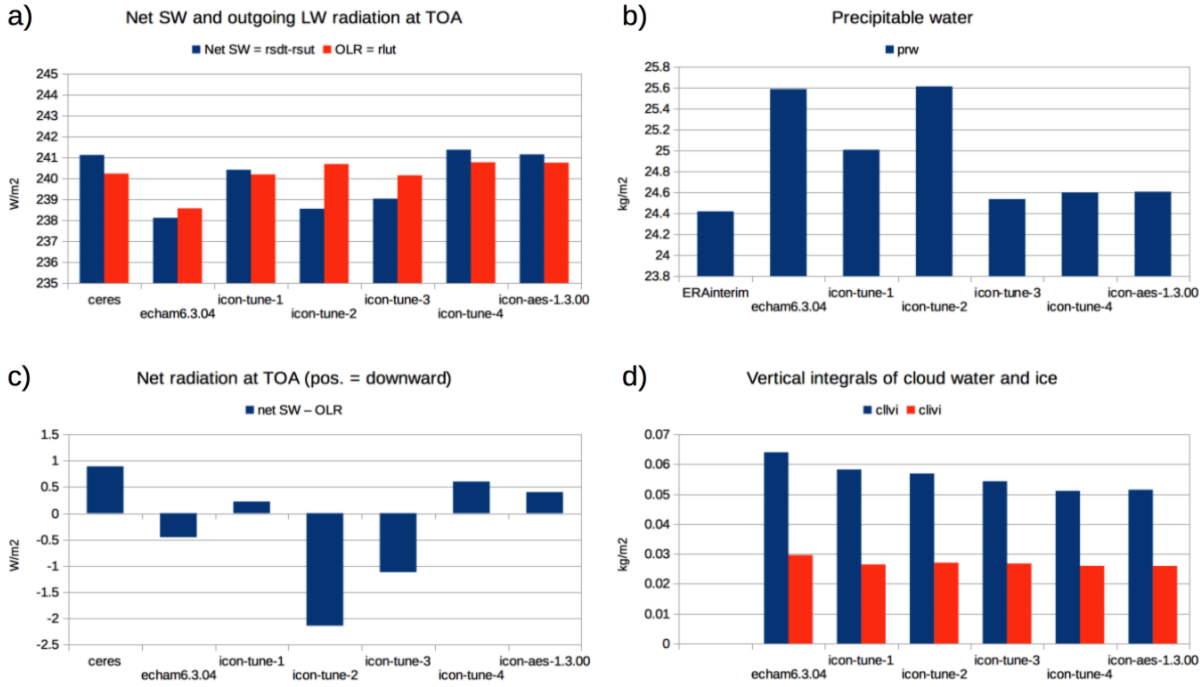
ICON-A tuning – Goals

- For usage in a coupled climate model
  - Near-zero energy balance at the top of the model atmosphere: ~0 – 1 W/m^2
    - Vertical integral of water vapor
    - Cloud cover
  - Small errors in ocean surface stress
    - Surface pressure
    - Wind

ICON-A tuning – Experiments

- icon-tune-1
  - Parameters as in echam-6.3.04-LR
  - Except for SSO scheme, because of different base topographic data
  - And a few changes: TTE scheme, let thin clouds rain
- icon-tune-2
  - For MJO: doubled entrainment of deep & mid-level conv., and down drafts
- icon-tune-3
  - Prandtl number for surface heat flux → atm. Moisture (cf. Pithan et al., 2015)
- icon-tune-4
  - Critical moisture for high clouds („crt“)
- icon-tune-5 = icon-aes-1.3.00
  - Sub grid-scale blocking and gravity waves

ICON-A tuning – Results

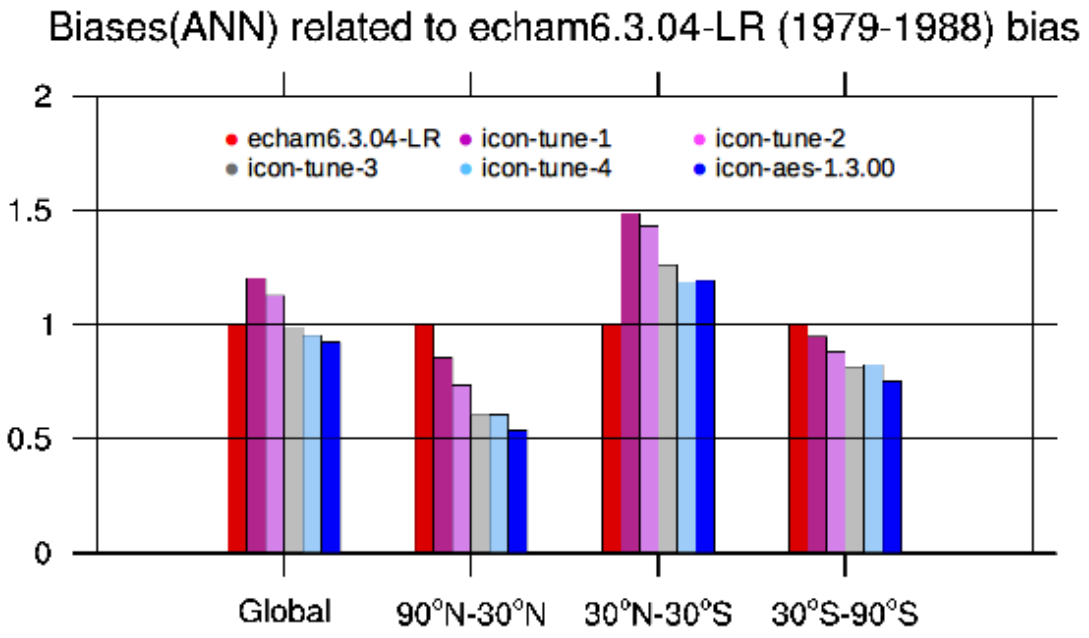


Multi variable biases

Quantity	Validation data	Period	Reference
air pressure at sea level	ERA interim	1979-2008	*Dee et al.* [2011]
toa outgoing longwave radiation	CERES	2001-2013	*Loeb et al.* [2012]
toa outgoing shortwave radiation	CERES	2001-2013	*Loeb et al.* [2012]
surface eastward wind stress	ERA interim	1979-2008	*Dee et al.* [2011]
surface northward wind stress	ERA interim	1979-2008	*Dee et al.* [2011]
column water vapor content	NVAP	1988-1999	*Randel et al.* [1996]
total precipitation over ocean	HOAPS	1988-2005	*Andersson et al.* [2010]
total precipitation over land	GPCP-V2.2	1979-2008	*Adler et al.* [2003]
surface land temperature	HadCRU4	1979-2008	*Jones et al.* [2012]
temperature (850 hPa)	ERA interim	1979-2008	*Dee et al.* [2011]
stationary waves (500 hPa)	ERA interim (geopotential)	1979-2008	*Dee et al.* [2011]
zonal mean temperature (up to 10 hPa)	ERA interim	1979-2008	*Dee et al.* [2011]
zonal mean zonal wind (up to 10 hPa)	ERA interim	1979-2008	*Dee et al.* [2011]

Multi variable biases

- Normalized by biases
  echam-6.3.04-LR → 1
- Extratropics:
  B(icon) < B(echam)
- Tropic:
  B(icon) > B(echam)
- Global:
  B(icon-aes-1.3) < B(echam)



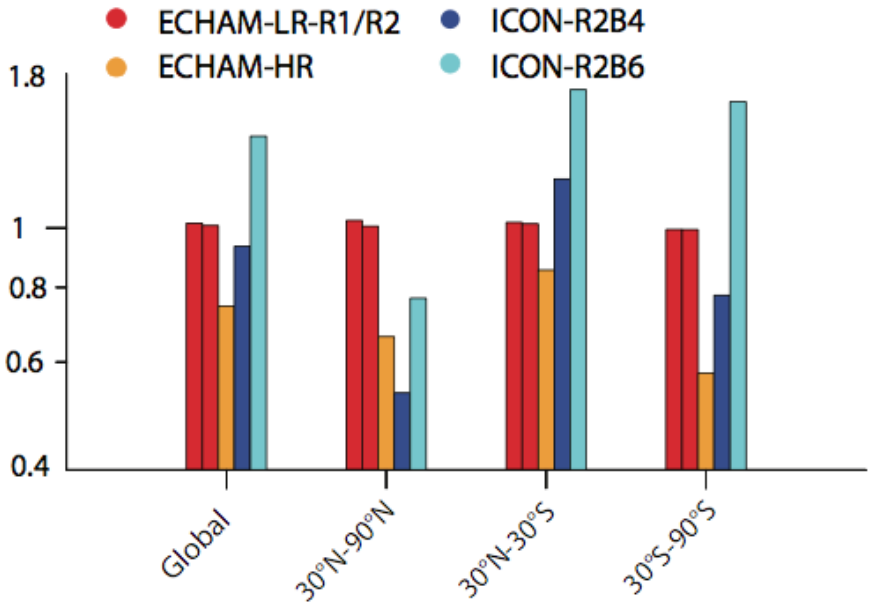
Model versions in Part 2

Name	Model version	Discretization	Grid Spacing	Tuning	Time step
ICON-R2B4	ICON-AES-1.3.00	R2B4, 47 z levels	160 km	Y	600 s
ICON-R2B6	ICON-AES-1.3.00	R2B6, 47 z levels	40 km	R2B4 settings	150 s
ECHAM-LR-(R1/R2)	ECHAM6.3.04	T63, 47 p levels	200 km	Y	450 s
ECHAM-HR	ECHAM6.3.04	T127, 95 p levels	100 km	Y	200 s

- ECHAM6-HR has doubled horizontal and vertical resolution compared to ECHAM6-LR
- ICON-R2B6 has quadrupled horizontal resolution, but same vertical resolution as ICON-R2B4

AMIP multi variable biases

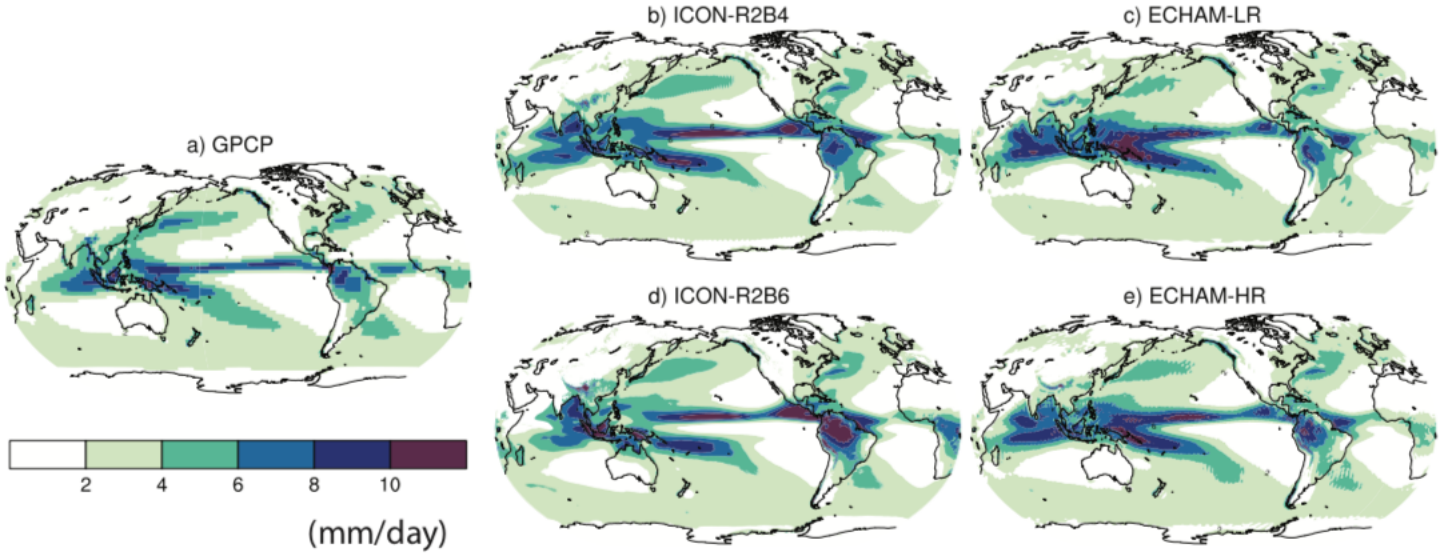
Part II: 1979-2008



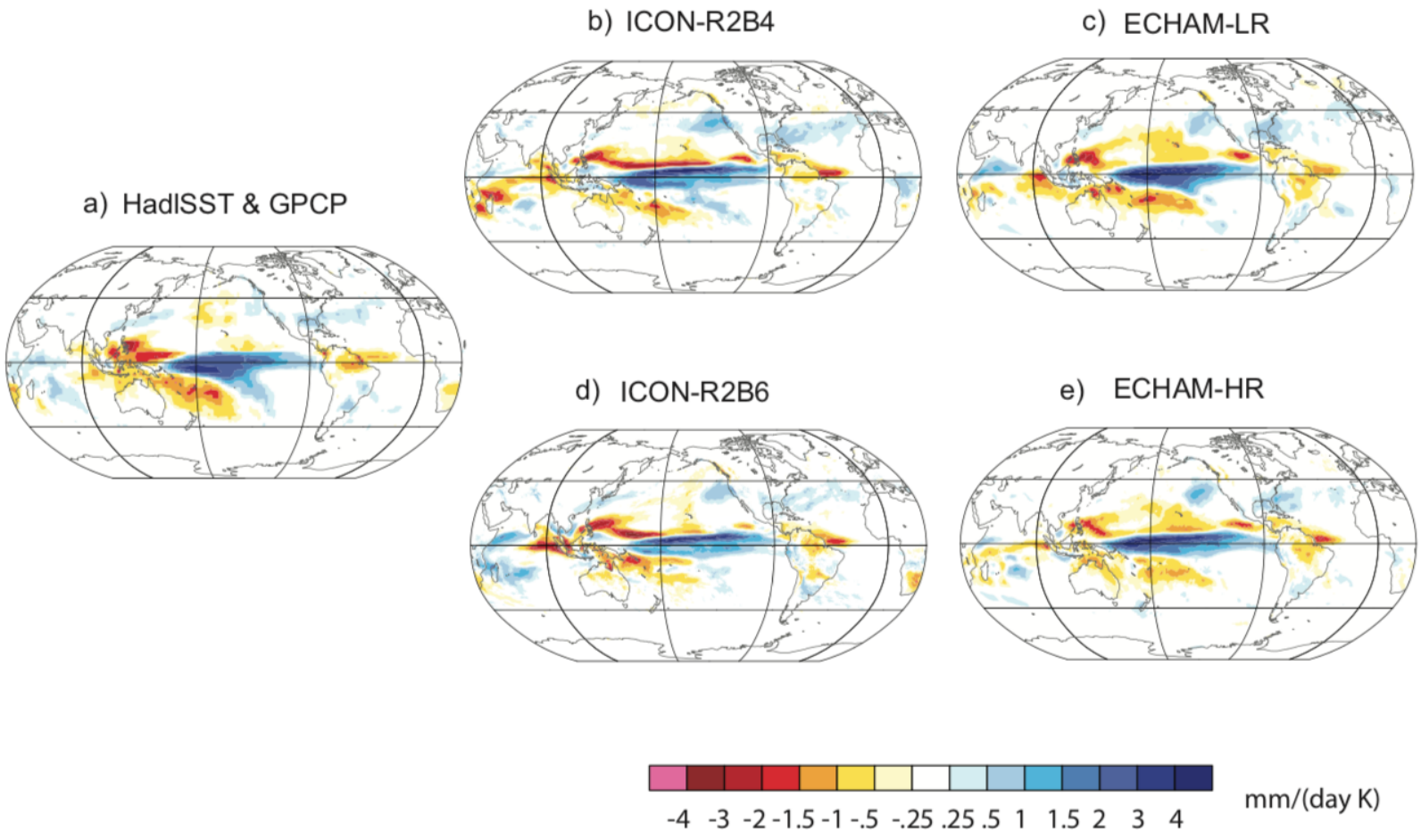
Observational datasets

Quantity	Name	Period	Reference
TOA radiative properties	CERES-EBAF-Ed4.0	2000/03-2016/02	*Loeb et al.* [2009]
Surface radiative properties	CERES-EBAF-Surface-Ed4.0	2000/03-2016/02	*Kato et al.* [2013]
Total cloud fraction	CALIPSO-GOCCP-v2.9	2006/06-2015/12	*Chepfer et al.* [2010]
Energy budget	SS12	2000-2012	*Stevens and Schwartz* [2012]
Barbados cloud fraction	Cloudnet (v0.10.2)	2011/01-2015/09	*Stevens et al.* [2016]
Leipzig cloud fraction	Cloudnet (v0.10.2)	2011/08-2015/12	n/a
Total precipitation daily	GPCP-V1.2	1979-2008	*Huffman et al.* [2001]
Total precipitation monthly	GPCP-V2.2	1979-2008	*Adler et al.* [2003]
Zonal mean temperature	ERA interim	1979-2008	*Dee et al.* [2011]
Zonal mean zonal wind	ERA interim	1979-2008	*Dee et al.* [2011]
Sea level pressure	ERA interim	1979-2008	*Dee et al.* [2011]
Sea surface temperature	HadISST1	1979-2008	*Rayner et al.* [2003]

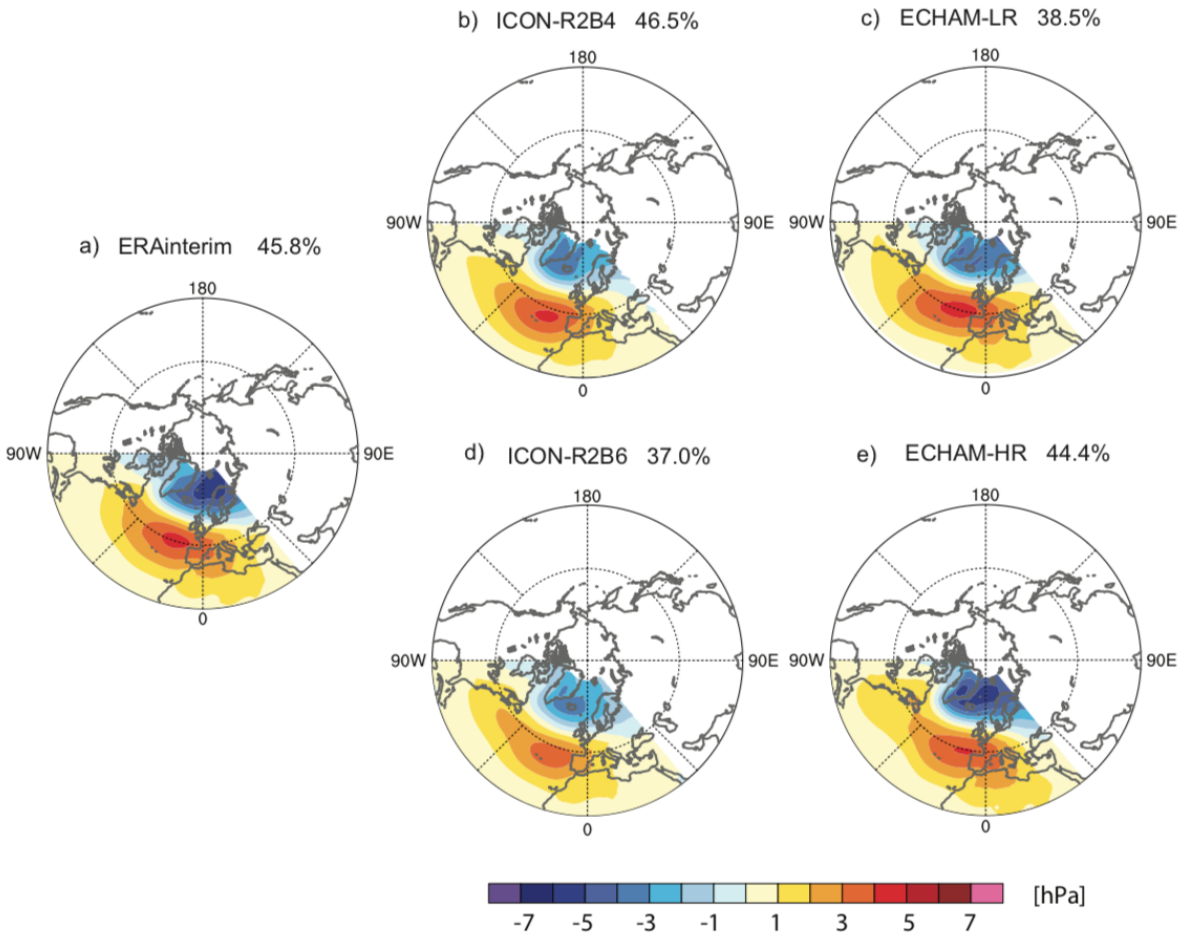
Precipitation climatology



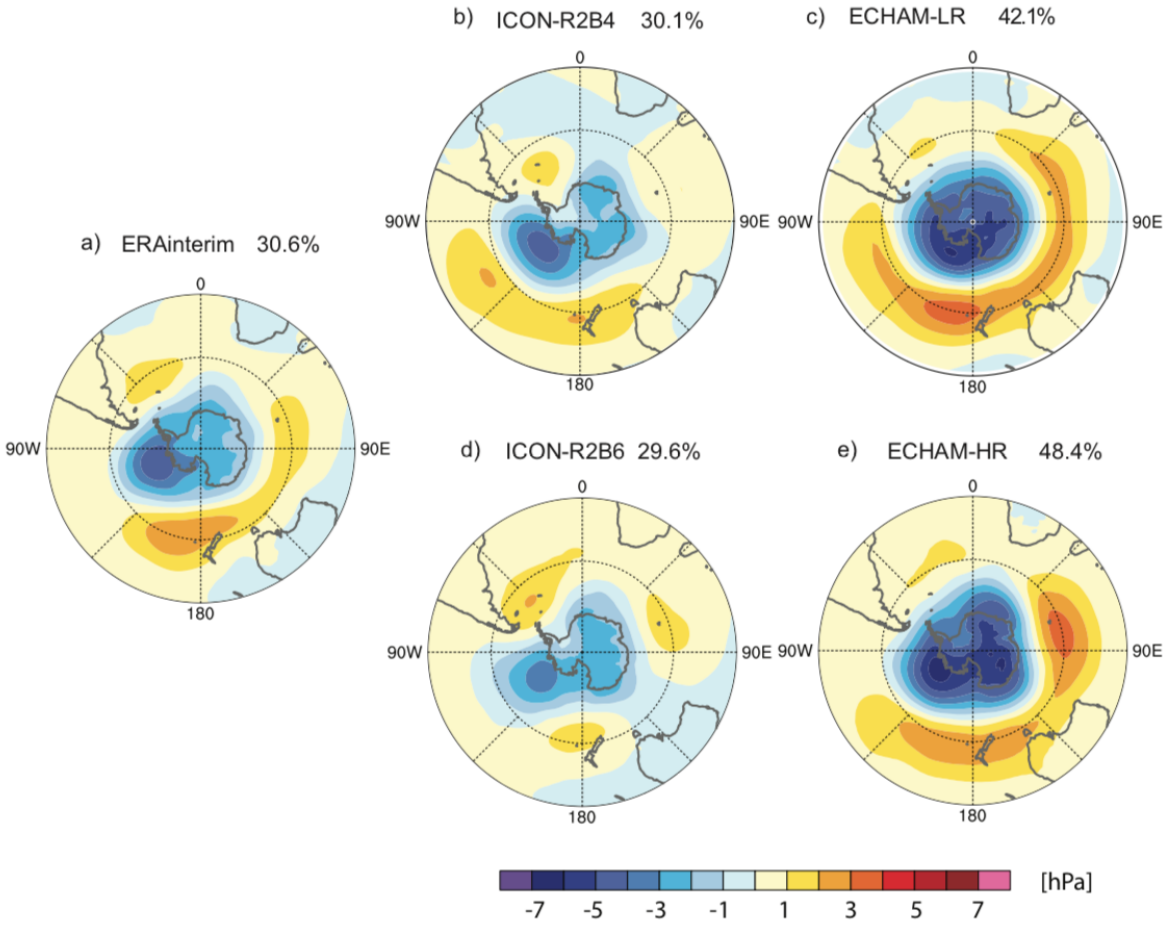
Precipitation response to the Niño 3.4 index, DJF



North Atlantic Oscillation (NAO)

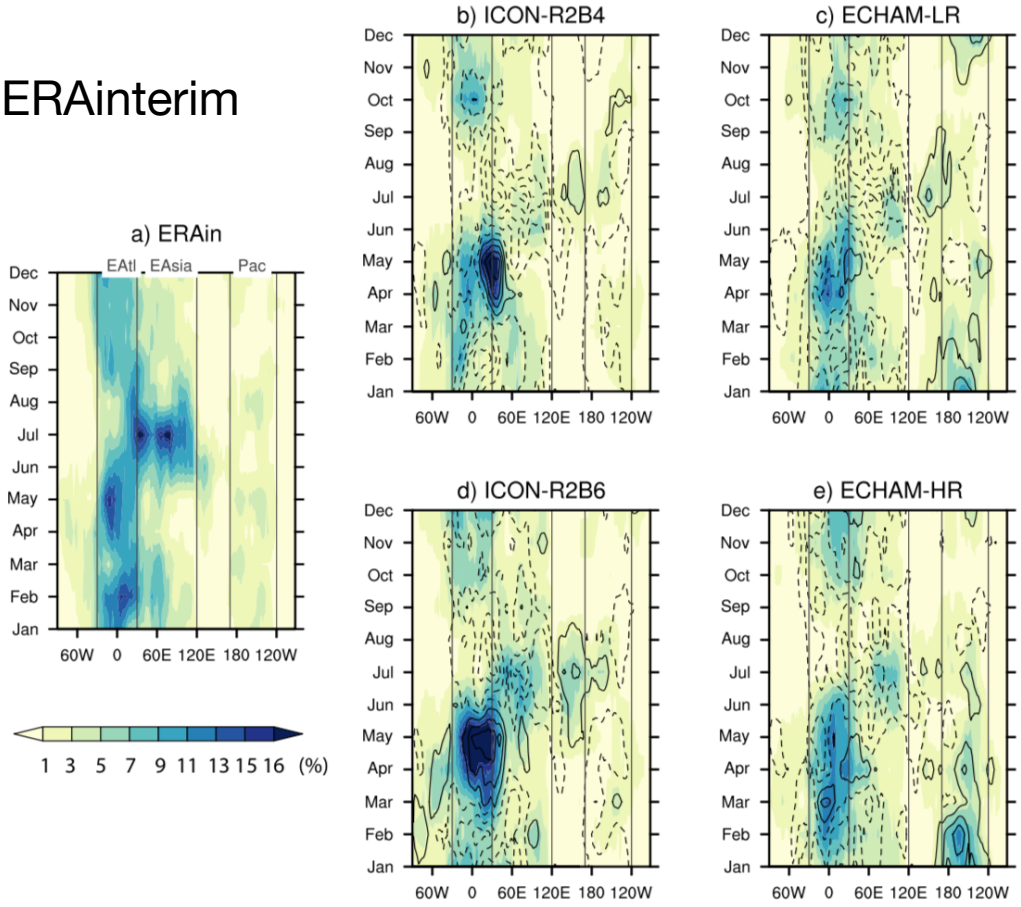


Southern Annular Mode in SON

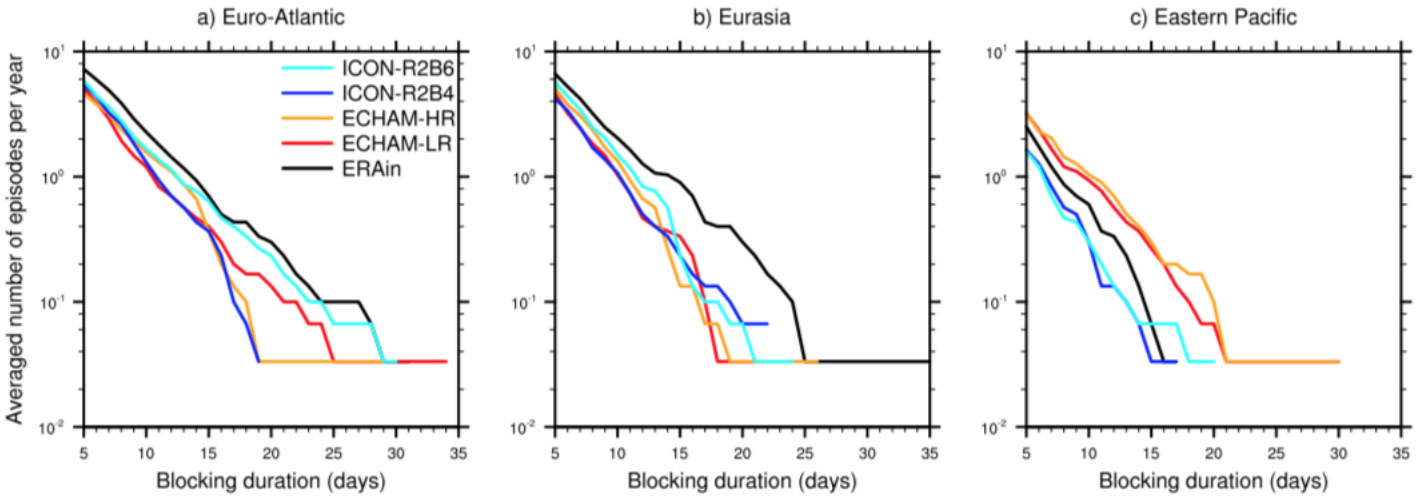


Monthly climatology of large-scale blocking episode frequencies (in %)

Contours = model - ERAinterim

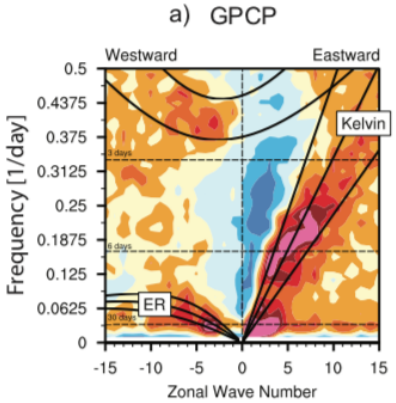


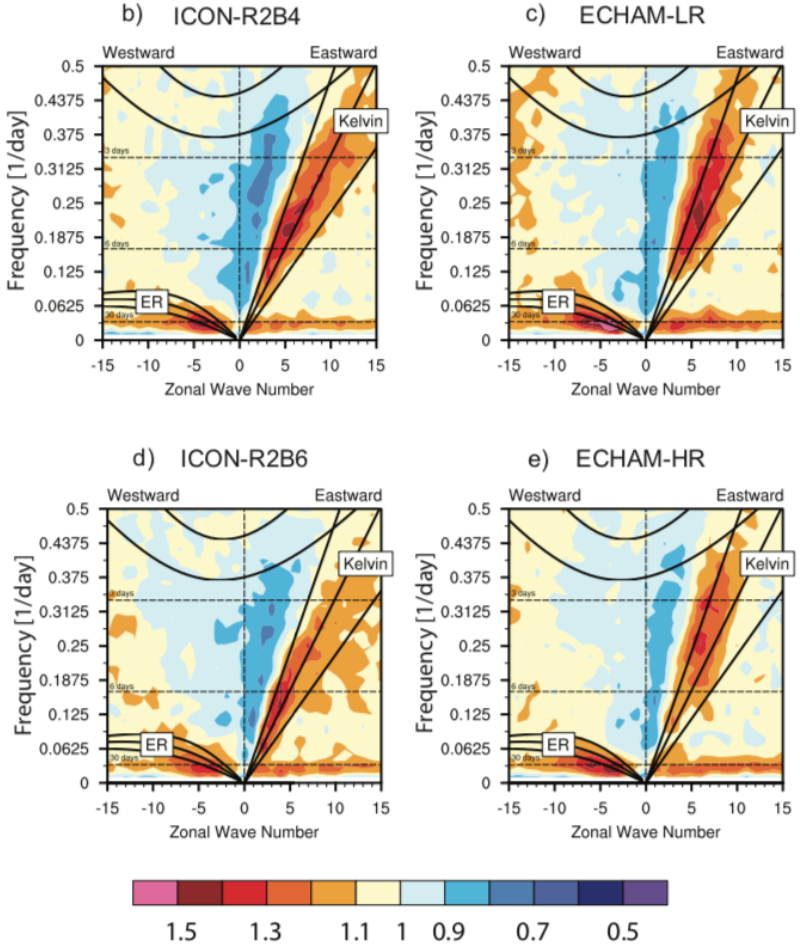
Number and duration of blockings



Wave number-frequency power spectra in precipitation, 13°N-13°S

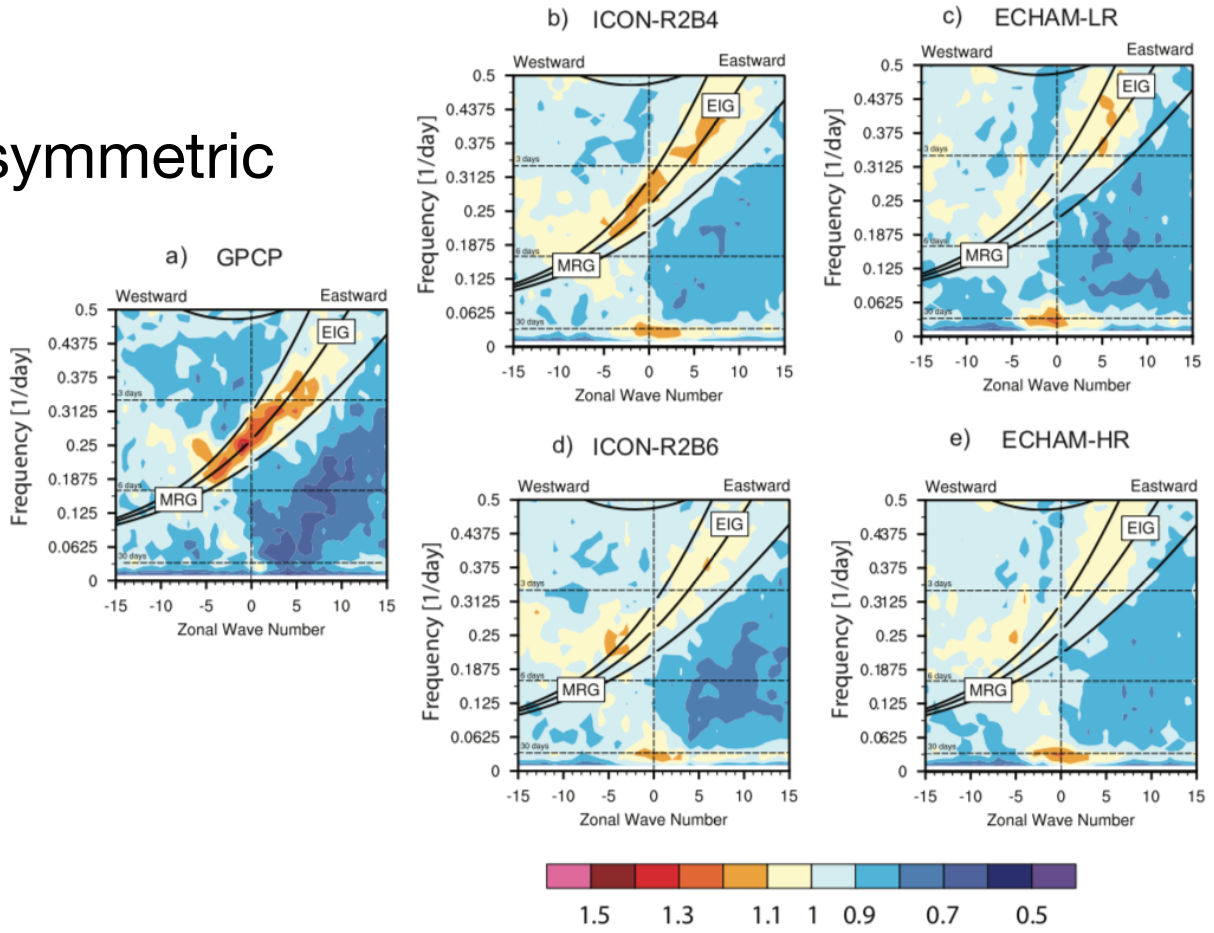
- Symmetric





Wave number-frequency power spectra in precipitation, 13°N-13°S

- Anti-symmetric



Summary

- Overall, … ICON-A provides a compelling representation of the mean climate and its variability.
- Its climate is similar to that of the last release of the well established ECHAM model
- The scope for improving a models climate by tuning is large, larger than simply increasing resolution without re-tuning the configuration. But resolution has benefits.
- Problems to be addressed:
  - Circulation of the middle atmosphere
  - Vertical distribution of clouds

Thanks for your attention