Assessing and understanding the role of stratospheric changes on decadal climate prediction

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Current knowledge …

… about the connection of the stratosphere to surface weather and climate

- Intra-seasonal predictability (see e.g. Gerber et al., 2012)
  - The impact of the stratosphere on troposphere forecast skill increases on intermediate time scales, from about a week to a season, but
  - the potential, for predictability can in particular be realised when the stratosphere is actively coupled with the troposphere, i.e. in the Northern Hemisphere winter and the Southern Hemisphere spring.
  - The downward coupling is characterised by the annular mode (dominant mode of intra-seasonal variability).
  - For instance, the Atlantic storm track region indicate a more negative NAO/AO in the easterly than westerly phase of the tropical quasi-biennial oscillation (QBO).

Current knowledge …

… about the connection of the stratosphere to surface weather and climate

- Inter-annual predictability
  - The stratosphere plays an important part in transmitting the tropical ENSO signal to mid-latitudes.
  - The stratosphere clearly acts in determining the climate response to volcanic and solar forcing.
  - Stratospheric circulation carries memory on inter-annual time scales in the QBO. Polar stratospheric dynamics are affected by the QBO because it modifies upward propagating planetary waves in the extra-tropics ("Holton-Tan").

Current knowledge …

… about the connection of the stratosphere to surface weather and climate

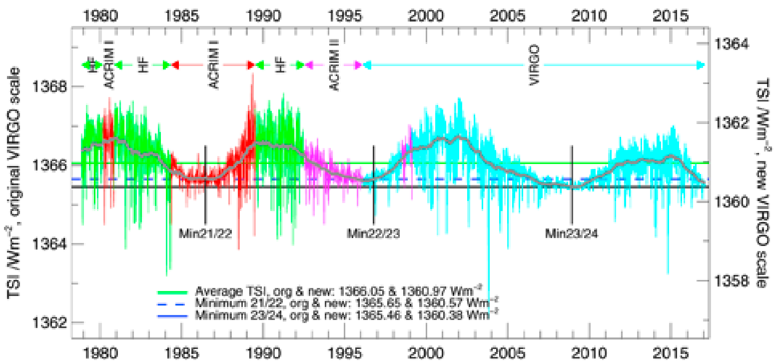
- Decadal predictability
  - On decadal time scales the impact of anthropogenic forcing on the stratosphere is expected to become significant.
  - Dynamical and chemical processes (and their feedback) in the stratosphere are changing which can affect the troposphere and therefore influence weather and climate. Significant effects are clearly detected in the Antarctic region (connection to the ozone hole; e.g. WMO, 2014).
  - Obviously the QBO is affecting surface (winter) climate. But further work is needed to robustly determine the QBO effect in seasonal to decadal climate predictions.

Open points, tasks

- Importance of the stratosphere for decadal climate prediction, in particular with respect to
  - the role of stratosphere-troposphere-ocean coupling (STRATO),
  - the influence of stratospheric solar forcing on decadal climate variability (STRATO),
  - the impact of decadal stratospheric variability on decadal climate variability (STRATO), and
  - the part of ozone-climate interactions on decadal scale (Fast-O3).
- Understanding of mechanisms (e.g. conducting sensitivity studies).
- Quantitative statements for improvement of the MiKlip prediction model due to the consideration of stratospheric processes.
- Analyses of the different MiKlip simulations.

Influence of the solar cycle on decadal climate projections

Decadal solar variability



2 Pathways

Bottom-up

Modulation of SSTs by changes in oceanic energy absorption through **total solar irradiance** variability

Top-down

Modulation of stratospheric temperature gradients and wind systems through variability in **spectral solar irradiance** and ozone, which affects interseasonal variability in the lower atmosphere

Decadal climate prediction

Main research questions

1. *How does decadal solar variability influence decadal climate projections?*
2. *How well is the solar signal represented in the MiKlip prediction system compared to other models and observations?*
3. *What model features (i.e. the radiation scheme, the resolution of the middle atmosphere or boundary conditions) are important for a realistic representation of the solar cycle?*

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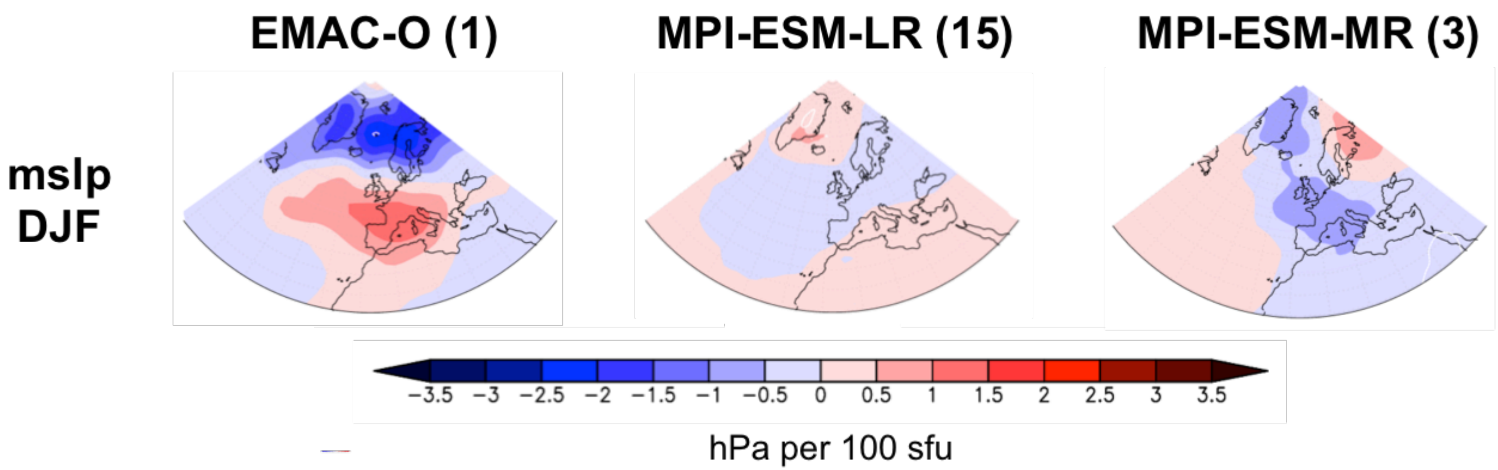
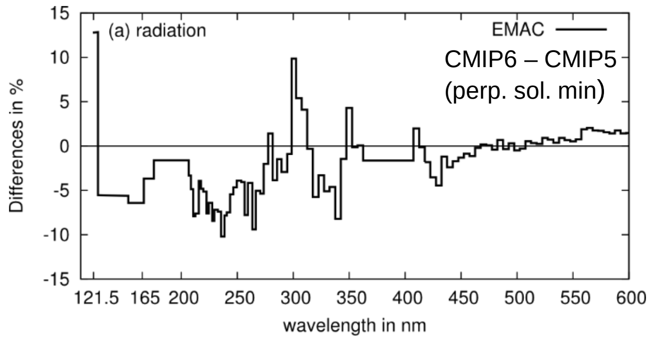
The decadal solar signal in the North Atlantic Sector

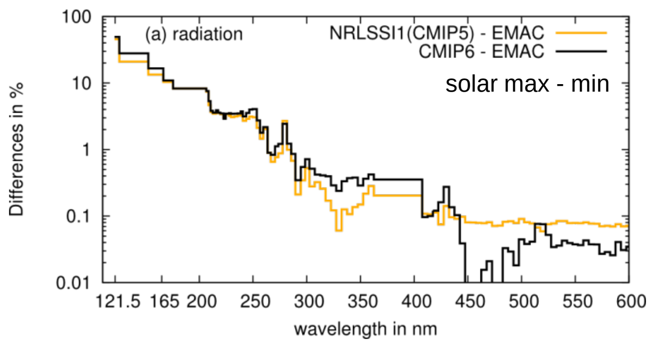


1. The solar signature in the troposphere resembles the positive phase of the NAO in coupled climate-chemistry-simulations with EMAC-O and observations.
2. Sensitivity studies with EMAC-O show that changes in the UV part of the solar spectrum may (partly) be responsible for the observed pattern **(Kubin et al., 2017** – to be submitted).
3. The early versions of the MPI-ESM-LR and -MR struggle to capture the observed solar signal in the North Atlantic Sector.
4. Reevaluation of the surface and middle atmosphere solar signal using the latest historical ensemble simulations of the updated MPI-ESM-LR and -HR prediction system.

→ **Poster presentation**

Differences between CMIP5 and CMIP6 - Solar Forcing

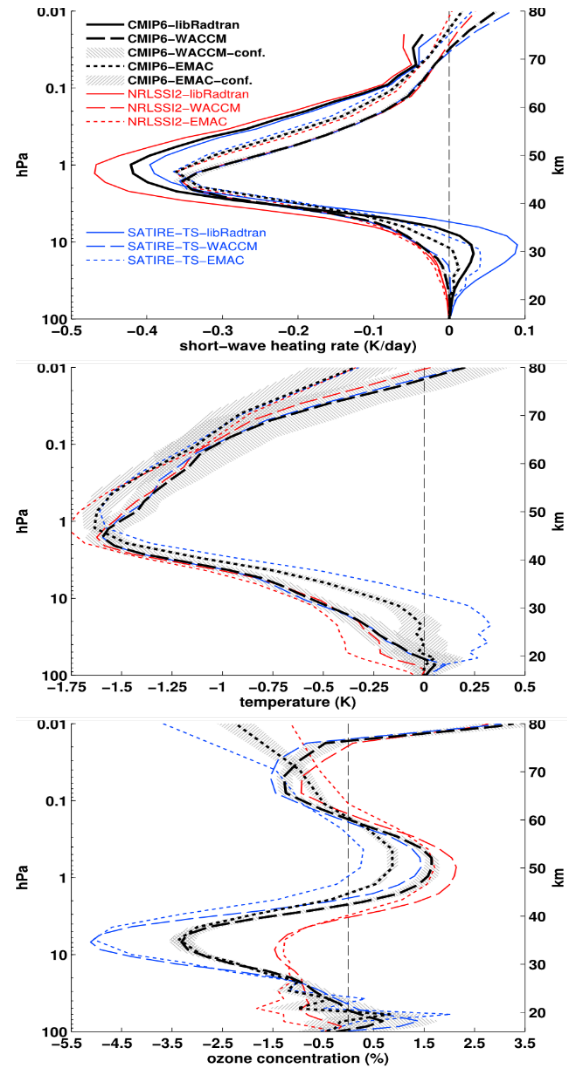




Lower CMIP6 Total Solar Irradiance value 1360.8 W/m²
vs. 1365.4 W/m² CMIP5

Matthes et al., 2016, GMD

Solar forcing for CMIP6:
NEW Datasets available!



Differences CMIP6-CMIP5
(25°N-25°S)

short-wave heating rates

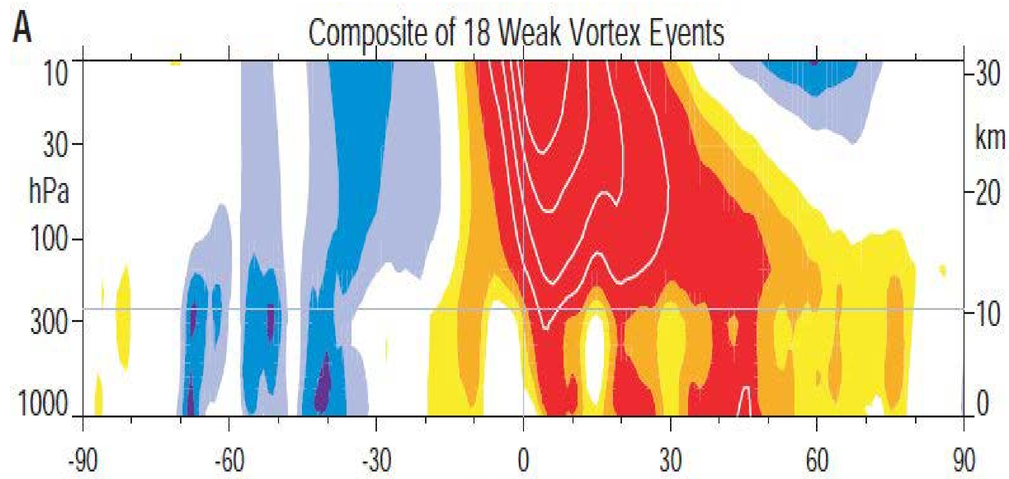
temperature

ozone concentration

Stratospheric dynamics and variability

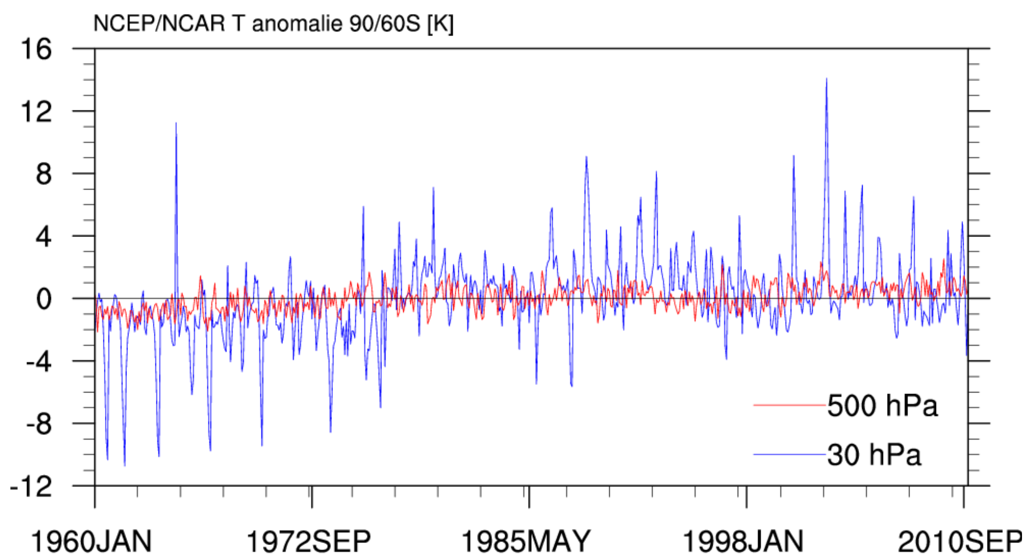
Understanding of

- Tropospheric-Stratospheric-Coupling

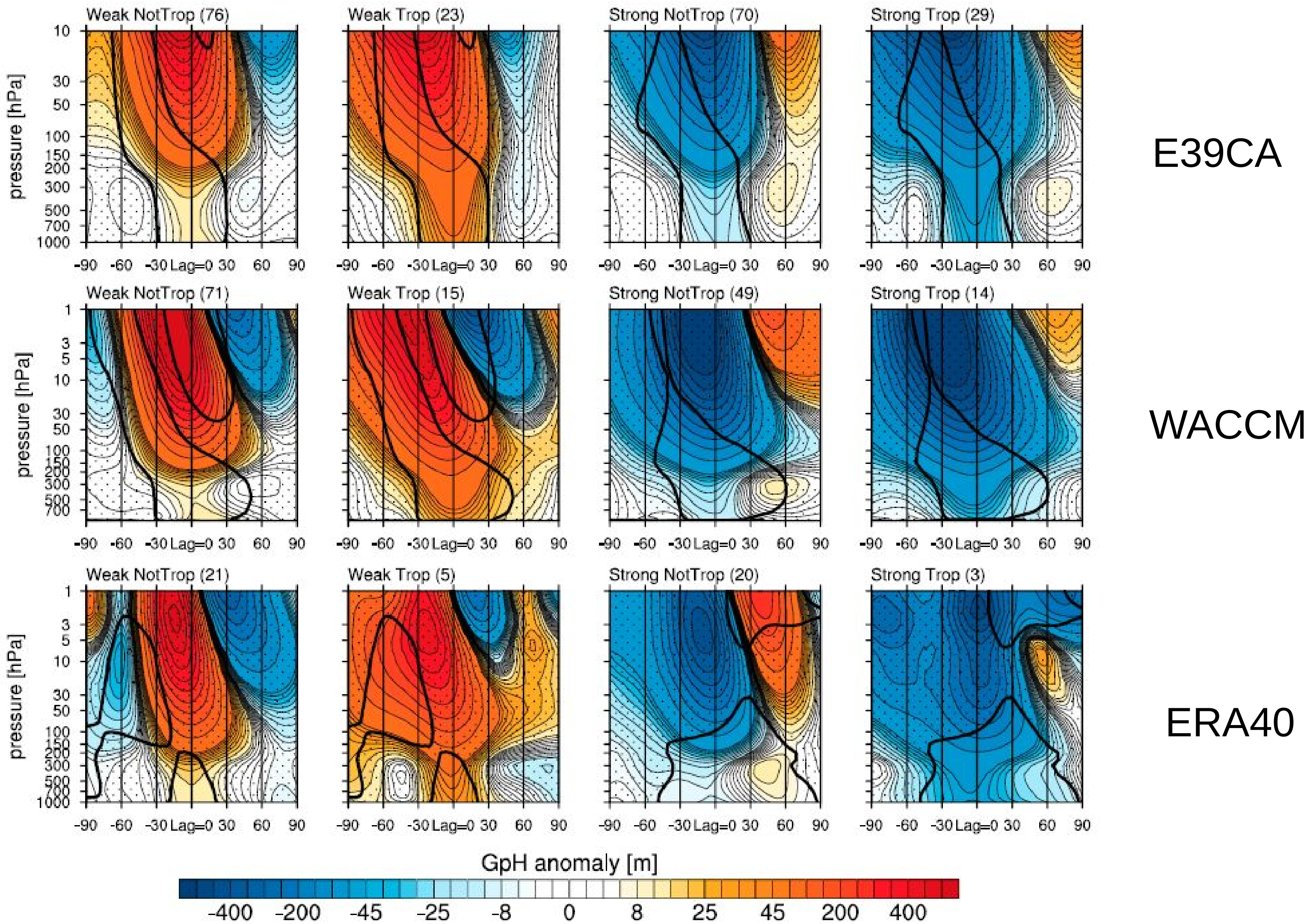


Baldwin and Dunkerton, 2001

- Variability of dynamics



Stratosphere-Troposphere coupling



Runde et al., GRL, 2016

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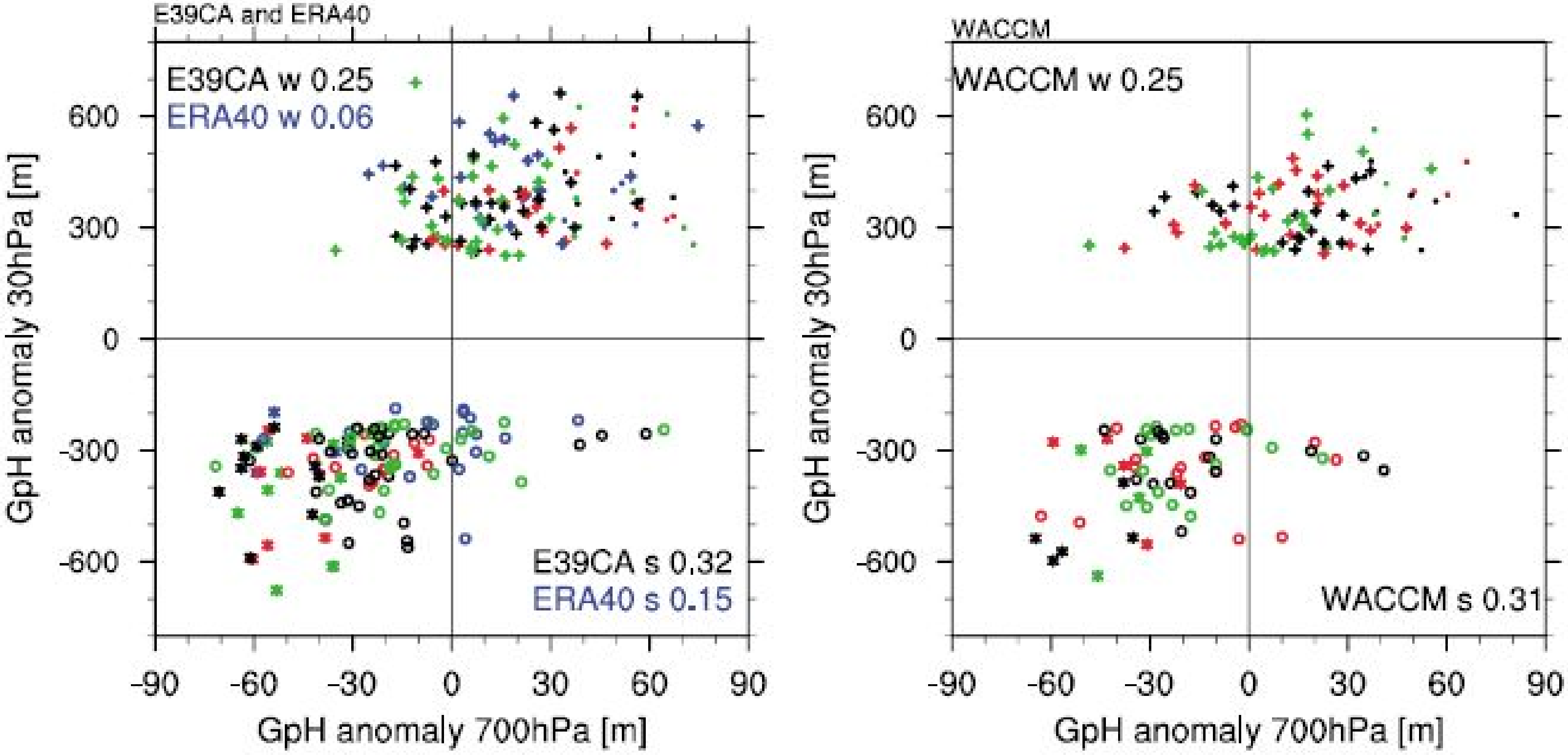
Stratosphere-Troposphere coupling



There is a high case-to-case variability of the anomalous stratospheric situations. Events of both types (Trop and NotTrop) span a large range of stratospheric GpH anomalies.

Dot (asterisk) denotes weak (strong) events of type Trop and plus (circle) denotes weak (strong) events of type NotTrop.

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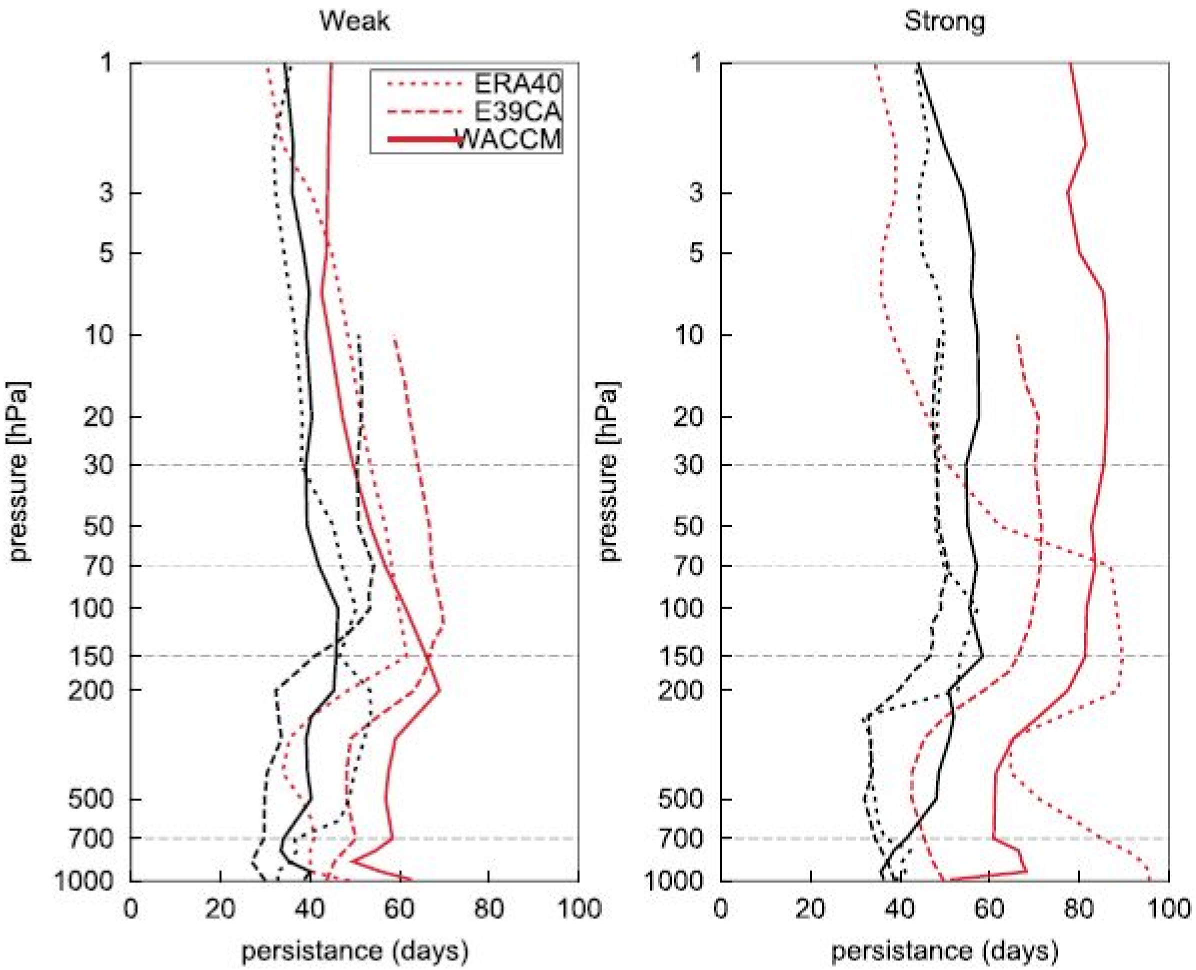
Runde et al., GRL, 2016

Stratosphere-Troposphere coupling



Persistence (i.e., duration of threshold exceedance) of weak and strong events of type **Trop** (red) and **NotTrop** (black) for ERA40 (dotted), E39CA (dashed), and WACCM (solid).

Runde et al., GRL, 2016

Variability of dynamics

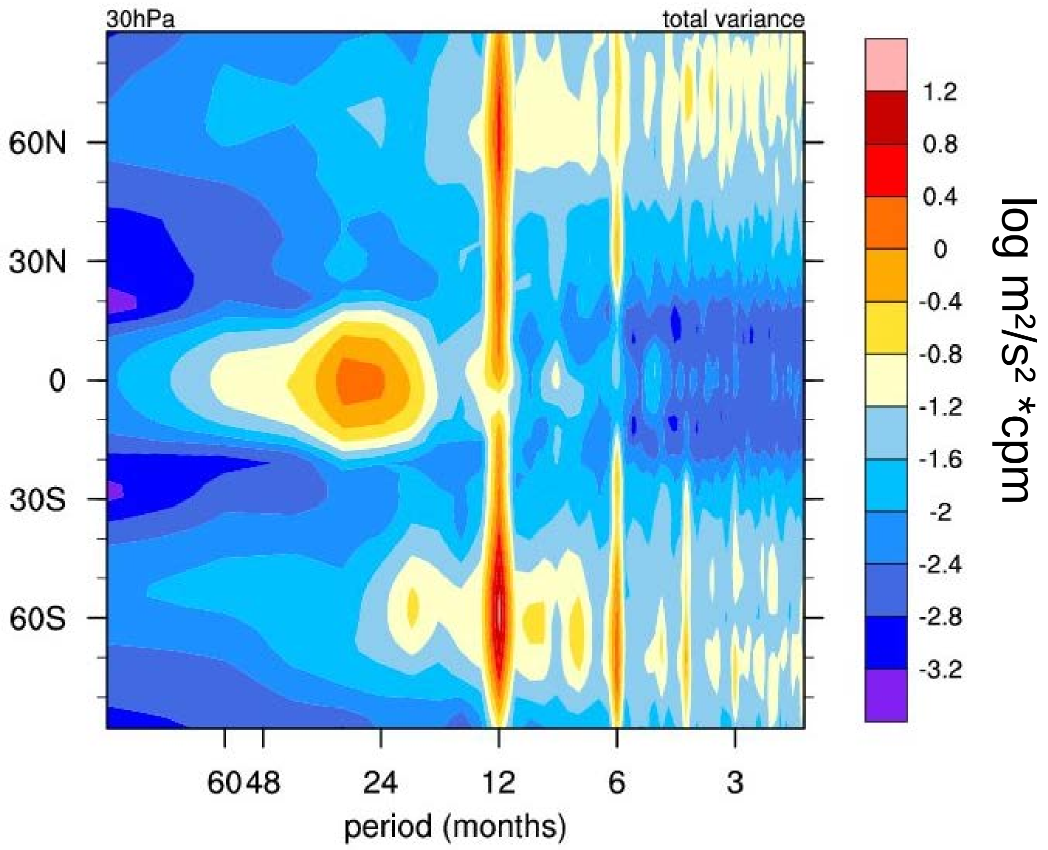
Example:

30 hPa zonal wind
(ERA-Interim)

Characteristics:

- QBO
- Annual + semi-annual cycle
- NH + SH stratospheric vortex

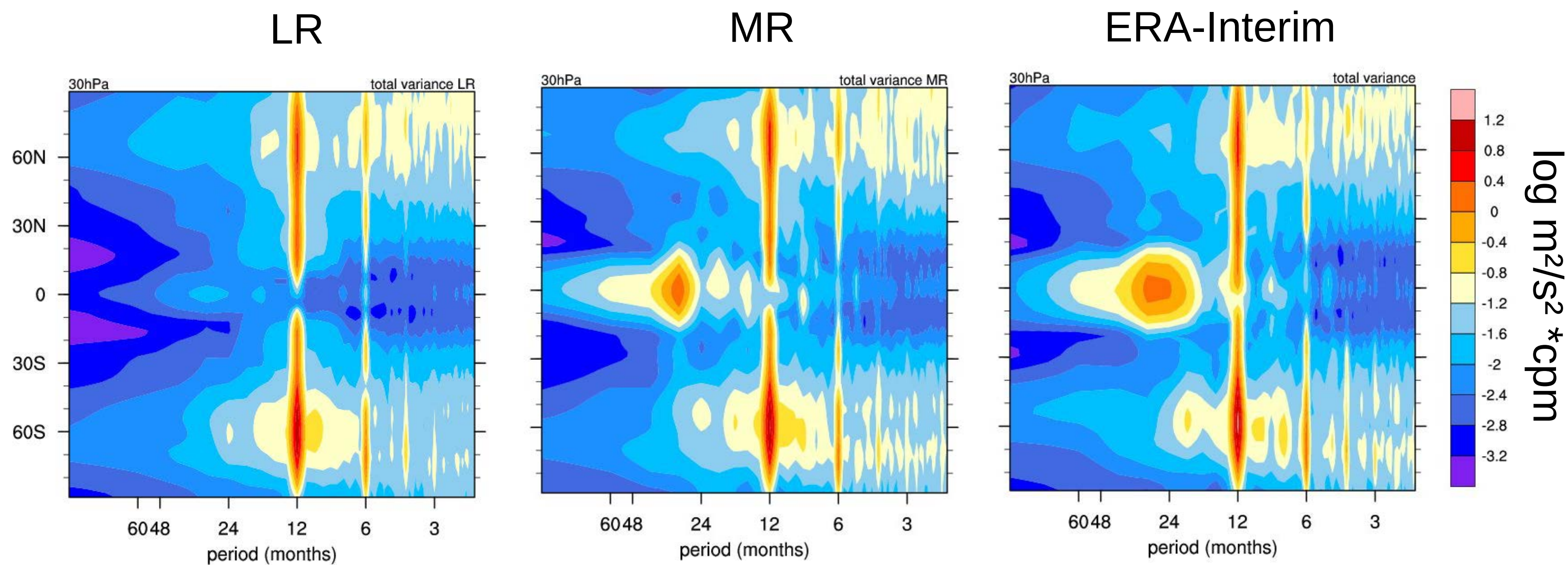
Decadal power spectral analysis (PSA)



Cai et al., ACPD, submitted, 2016

Variability of dynamics

Power spectra (total variance, 30 hPa), zonal wind

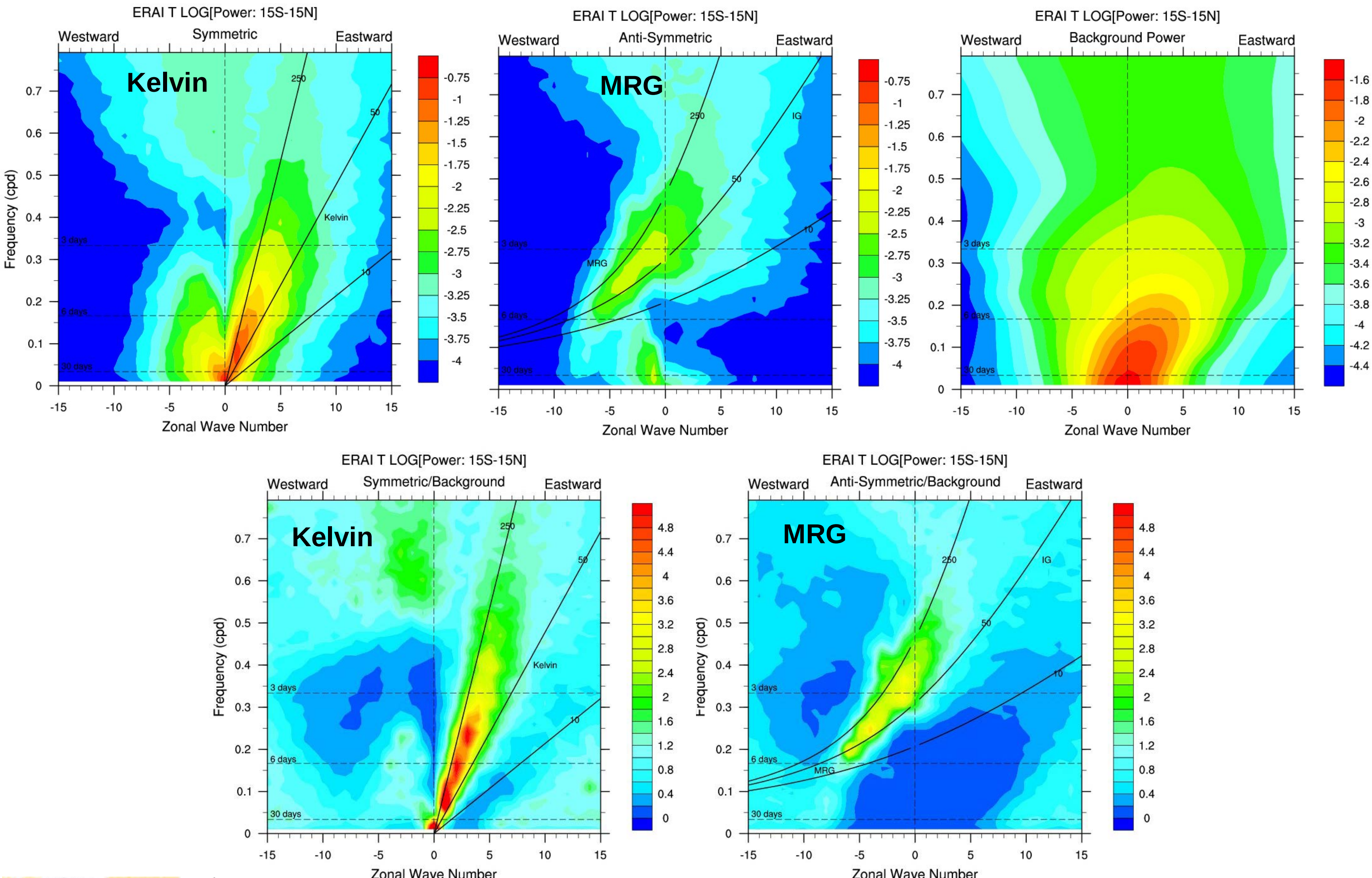


Model* deficits in the polar vortices and the QBO!

[* Sensitivity studies with EMAC (time slice simulations); results are qualitatively very similar in comparison with MiKlip prediction model results presented and discussed in MiKlip I).]

Cai et al., ACPD, submitted, 2016

Variability of dynamics (ERAI)



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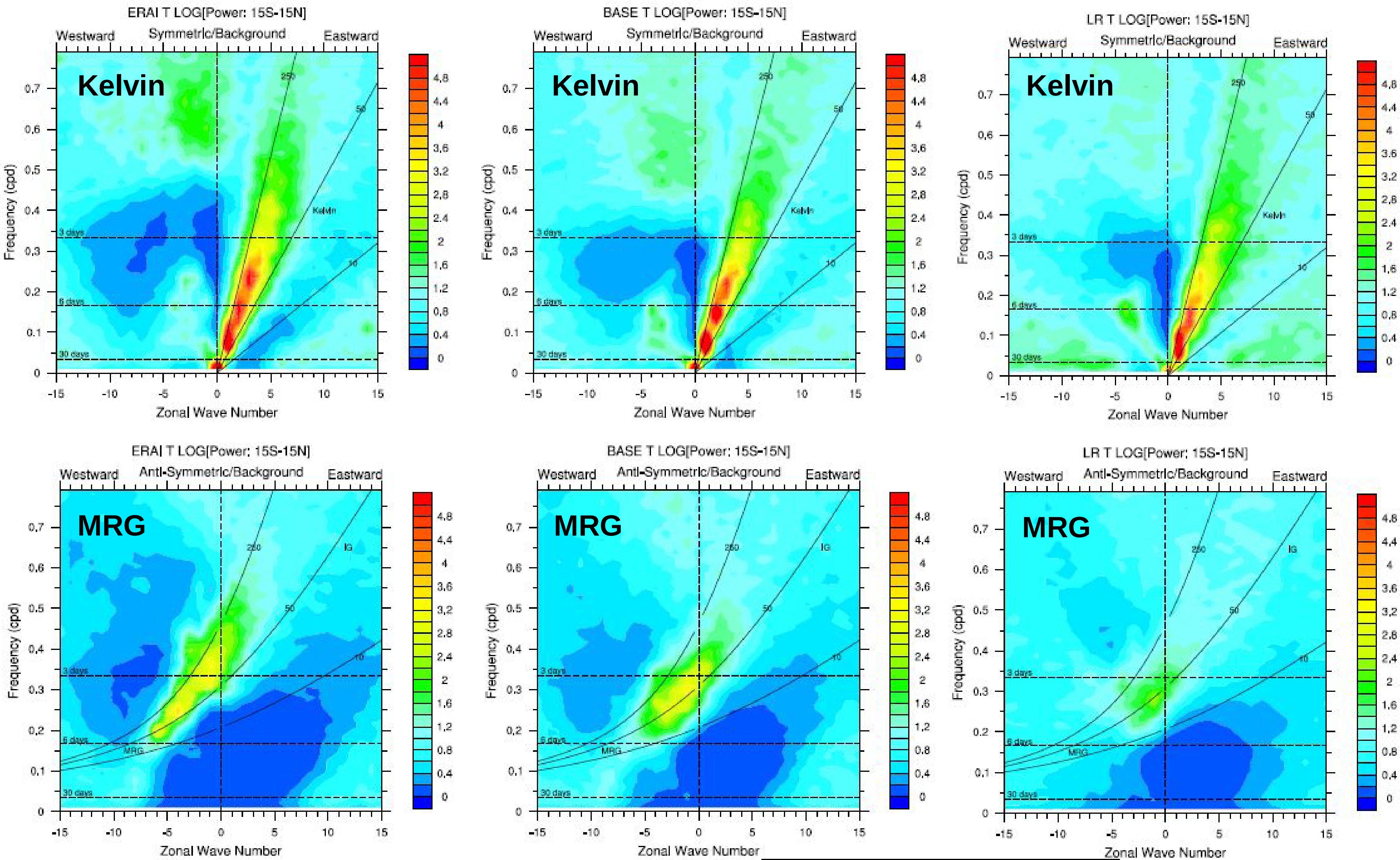
Cai et al., ACPD, submitted, 2016

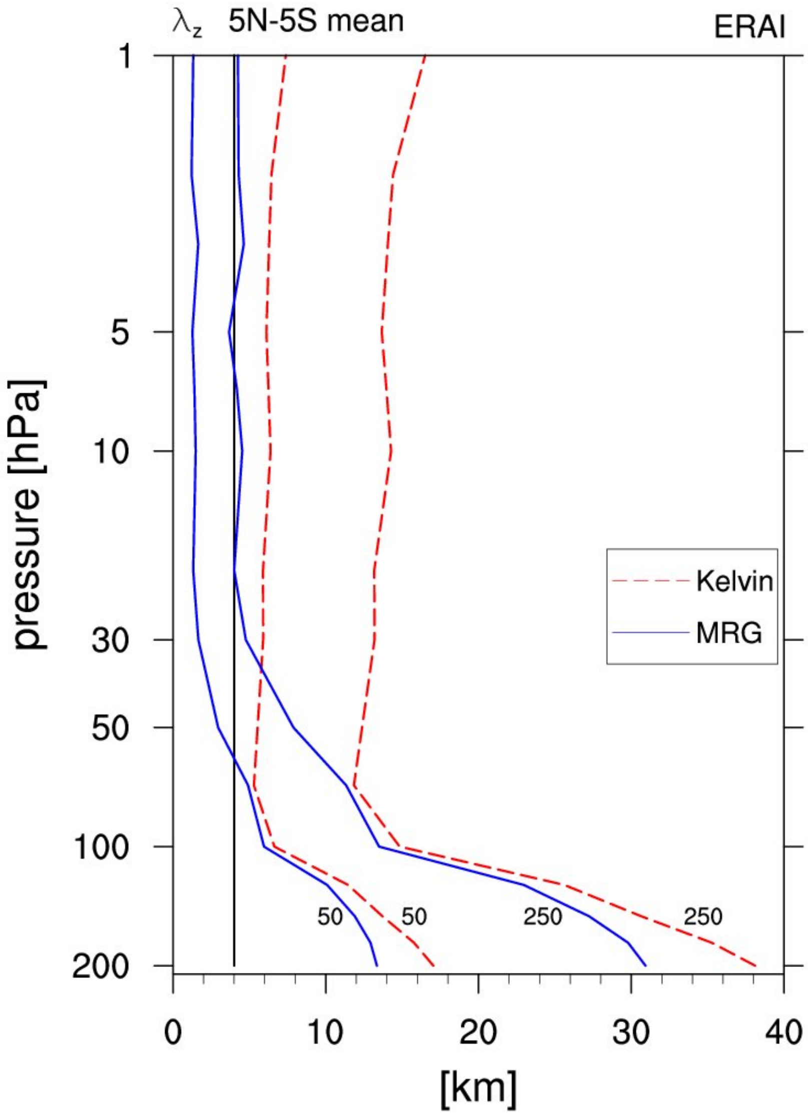
Variability of dynamics



(a) ERAI (b) BASE ← EMAC simulations → (c) LR

Cai et al., ACPD, submitted, 2016

Variability of dynamics



Approximation of vertical distribution of vertical wavelengths calculated for MRG and Kelvin waves with equivalent depths of 50 and 250 m. The **black vertical line** marks the 4 km, which is the smallest resolvable vertical wave-length by the LR model.

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Cai et al., ACPD, submitted, 2016

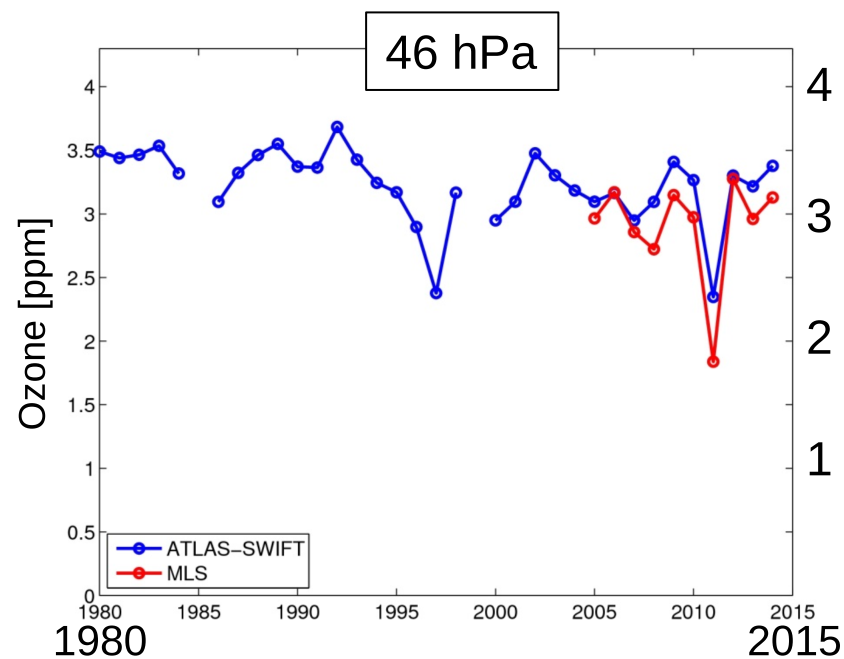
Fast ozone chemistry for climate models

- Ozone usually prescribed in climate models, since detailed calculation computationally very expensive, e.g. in IPCC CMIP5 models.
- Desirable to include interactive ozone in climate models due to important ozone-climate interactions on decadal scale.
  - Considering the effect of changes in polar stratospheric vortex and ozone on surface temperature trends in Antarctica and Arctic (e.g. Thompson and Solomon, 2002; Ivy et al., 2017).
  - Strong stratospheric ozone anomalies can have a significant surface impact (Smith and Polvani, 2014; Calvo et al., 2015).
  - Allowing ozone-circulation feedback and its implications for climate change (Nowack et al., 2015).

Fast ozone chemistry for climate models

- Develop fast stratospheric chemistry scheme SWIFT for implementation in climate models
  - Validation with measurements and respective ensemble simulations with EMAC-SWIFT
  - Implementation of SWIFT into MPI-ESM1.1
  - Provide ozone fields for the MiKlip prediction system

Interannual ozone variability in the Arctic stratosphere:
Vortex averaged ozone in polar spring from SWIFT in ATLAS CTM and MLS satellite observations



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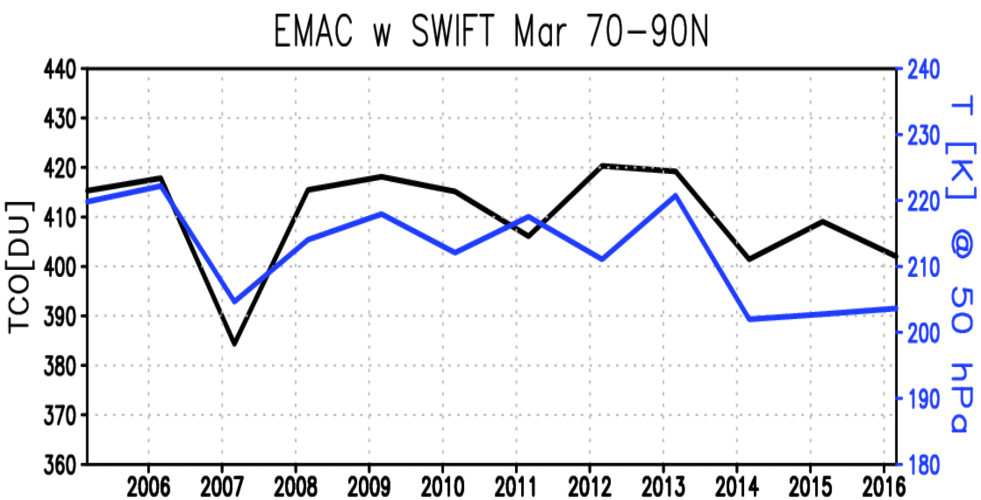
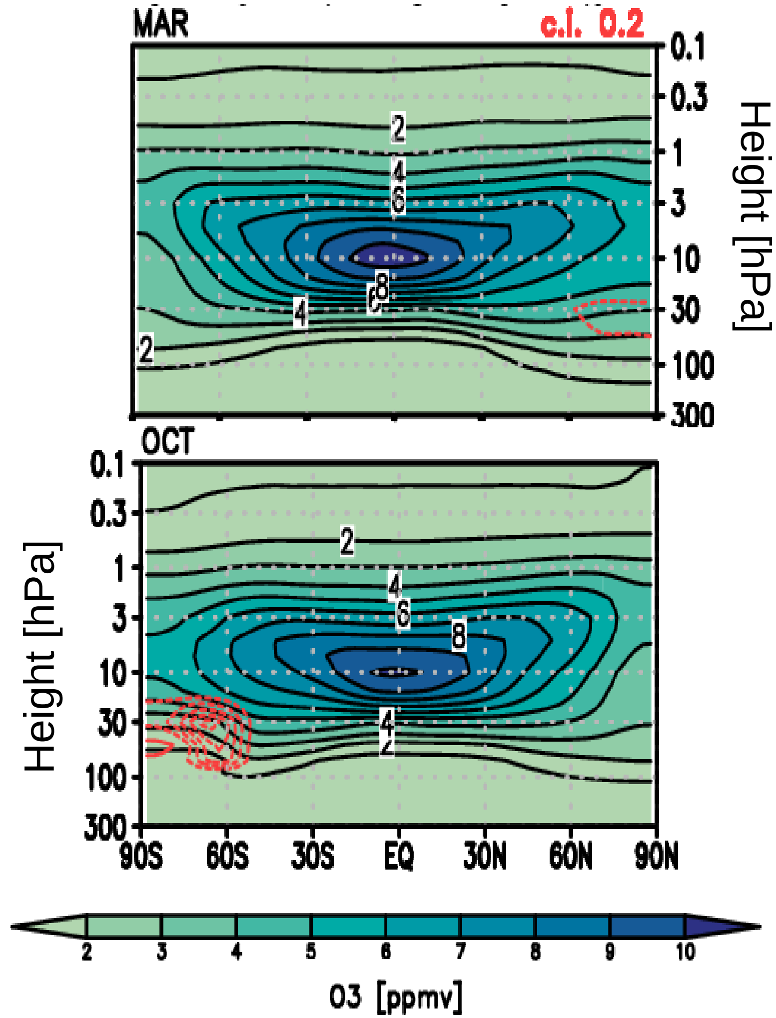
SWIFT – a fast interactive ozone scheme



Total ozone column (black) and temperature at 50 hPa (blue) in the North Polar region from 2005 to 2016:

EMAC with SWIFT can simulate varying polar ozone depending on the simulated state of the atmosphere.



Monthly mean for model years 2005-2016

Ozone anomaly to climatology [ppmv]

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General conclusions (STRATO and Fast-O3)

- Atmosphere-ocean coupling and solar forcing
  - Solar cycle reproduces a NAO(+) signal in the North Atlantic sector.
  - Model results (sensitivity studies with EMAC-O) indicate that changes in the UV part of the solar spectrum may in part be responsible for the observed pattern.
- Stratospheric variability
  - Extreme events in the Northern Hemisphere affect the troposphere, particularly in winter and early spring (Runde et al., 2016; Ivy et al., 2017).
  - High vertical resolution of less than one kilometer for the MiKlip prediction system is required to resolve the full spectrum of planetary waves (Cai et al., 2016). A realistic QBO is needed for adequate simulation of extra-tropical stratospheric variability .
  - A realistic reproduction of the QBO may improve the skill of decadal prediction, but further work needed (e.g. Scaife et al., 2014).
- Feedback with chemistry (here in particular ozone!)
  - Realistic description of ozone (spatial distribution and development over time) is necessary, particularly in the North Polar region, which is consistent with the dynamic field (circulation) of the stratosphere; it should improve decadal climate prediction.