3D climate simulations of Earth-like planets with a range of atmospheric composition, radiative transfer, ocean, and resolution configurations, using the new version of ROCKE-3D

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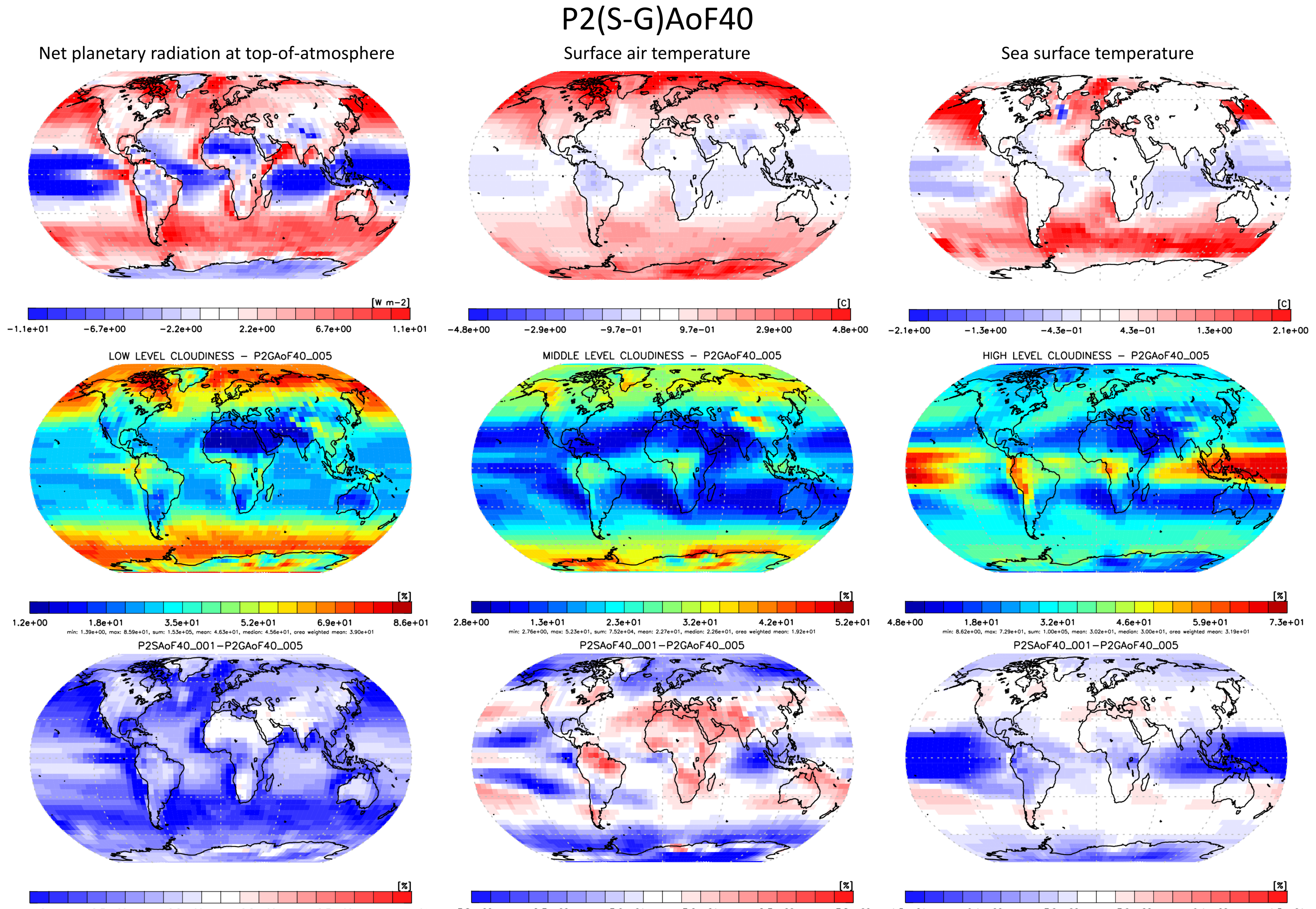
Abstract

Understanding the climate of terrestrial planetary atmospheres has been increasingly the focus of research worldwide, in light of the increasing amount of rocky planet discoveries orbiting other stars in or near their habitable zone. Here we present simulations with the new version of the 3D climate model ROCKE-3D, whose version 2.0 will soon become publicly available. A wide range of configurations will be supported, compared to a handful ones in its predecessor, version 1.0 (Way et al., 2017). These include two model resolutions (4x5 and 2x2.5), two radiation schemes (GISS and SOCRATES), three atmospheric configurations (Earth-like, Earth-like without O3 and aerosols, and N2-dominated), and three ocean setups (prescribed sea-surface temperatures and ice cover, q-flux, and dynamic). Simulations of all different configuration combinations have been performed and will become available for use by the community. Key results will be presented across those configurations, together with the role of the structural uncertainty in model setup in the resulting climate calculated by the model.

Radiation

Two fundamentally different radiation schemes have been used: the first is the GISS radiation (G), which is strongly optimized for present-day and paleoclimate Earth applications, and the other is the SOCRATES radiation (S), whose implementation in ROCKE-3D has been presented in Way et al. (2017).

P2(S-G)AoF40



The SOCRATES radiation (simulation P2SAoF40, which includes the preindustrial Earth atmospheric composition and dynamic ocean) generates less low and high clouds when compared against the GISS scheme (simulation P2GAoF40). The net effect of the former is to trap more heat than the simulations with the GISS radiation, resulting in a warming that is more evident in the higher latitudes. On the other hand, high clouds make the planet more reflective as a net effect, resulting in less radiation (and a cooler simulation) in the tropics when using SOCRATES, compared to when using GISS radiation.

In ROCKE-3D 2.0 we provide template configurations for an Earth-like atmosphere with conditions similar to preindustrial (year 1850), which include combinations of two radiation schemes, three different atmospheres, three ocean configurations, and two horizontal resolutions, resulting in a total of 36 supported configurations.

Preferred model to use: P2SNo{F,M}40

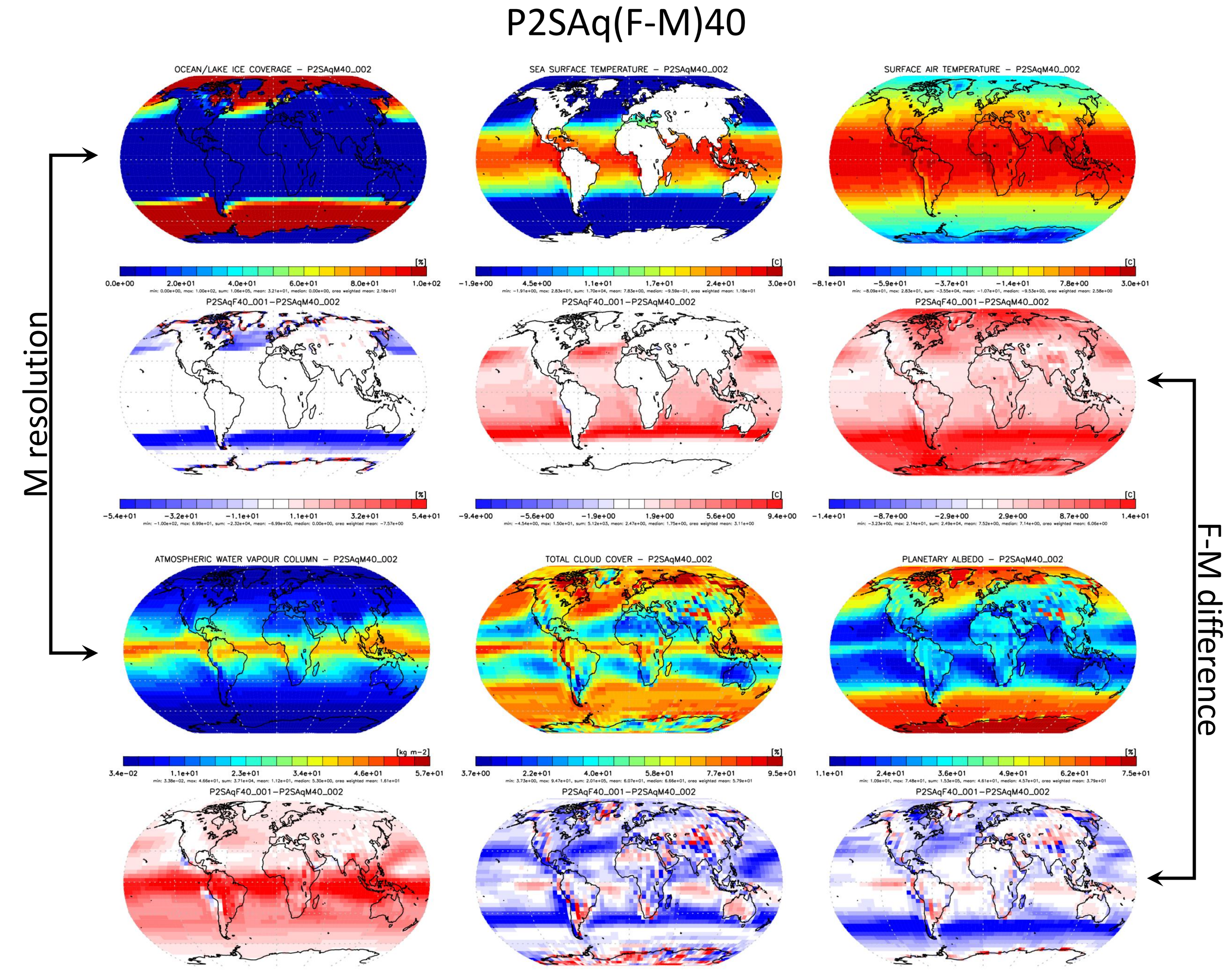
Model configurations: P2{G,S}{A,N,x}{,q,o}{F,M}40

Component	Abbreviation	Meaning
Model version	P2	Template configuration of planet 2.0 version of ROCKE-3D
Radiation	{G,S}	G: GISS radiation
		S: SOCRATES radiation
Atmosphere	{A,x,N}	A: Atmosphere of preindustrial Earth, as described by GISS ModelE CMIP6 simulations for the year 1850
		x: Same as A, without a) aerosols; b) O_3; c) stratospheric H_2O formation from CH_4 oxidation
		N: Same as x, with O_2 and Ar replaced by N_2
Ocean	{,q,o}	<no letter>: prescribed sea surface temperature and sea ice extent and thickness
		q: qflux ocean, 100m mixed layer depth, zero heat transport
		o: dynamic ocean; see next lines for resolution
Resolution	{F,M}40	F40: atmosphere: 2°x2.5° with 40 layers to 0.1 hPa; ocean, if o configuration: 1°x1.25° with 40 layers
		M40: atmosphere: 4°x5° with 40 layers to 0.1 hPa; ocean, if o configuration: 4°x5° with 13 layers

Resolution

In ROCKE-3D 2.0 we only kept the 20 layer model version as a legacy option, and opted to use for all simulations the 40 layer version. We also decided to use both the M and F resolutions, in order to be able to resolve with greater accuracy larger-than-Earth planets and fast rotators.

P2SAq(F-M)40

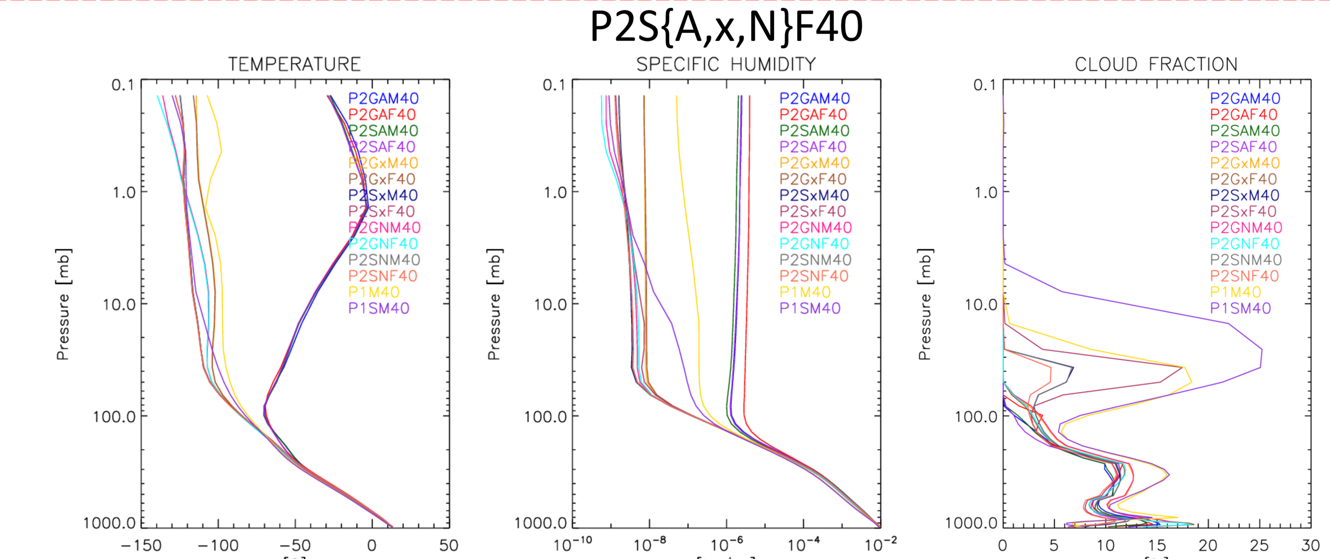


Major changes are calculated when using the zero q-flux ocean and change the resolution from M to F, which is not the case for the prescribed SST runs (dynamic ocean runs still underway). A global mean 2.5°C increase in temperature alters climate dramatically.

Atmospheres

In ROCKE-3D 1.0 we only provided template configurations for one type of an atmosphere, that of preindustrial Earth but without atmospheric aerosols, O_3, and stratospheric formation of H_2O from CH_4 oxidation (named x in 2.0). In ROCKE-3D 2.0 we decided to keep this configuration (x), but also included two additional configurations: 1) the exact atmosphere of preindustrial Earth for the year 1850 (named A), and 2) the same atmosphere but without aerosols, O_3, stratospheric formation of H_2O from CH_4 oxidation, and the O_2 and Ar of the atmosphere replaced with N_2 (named N).

P2S{A,x,N}F40

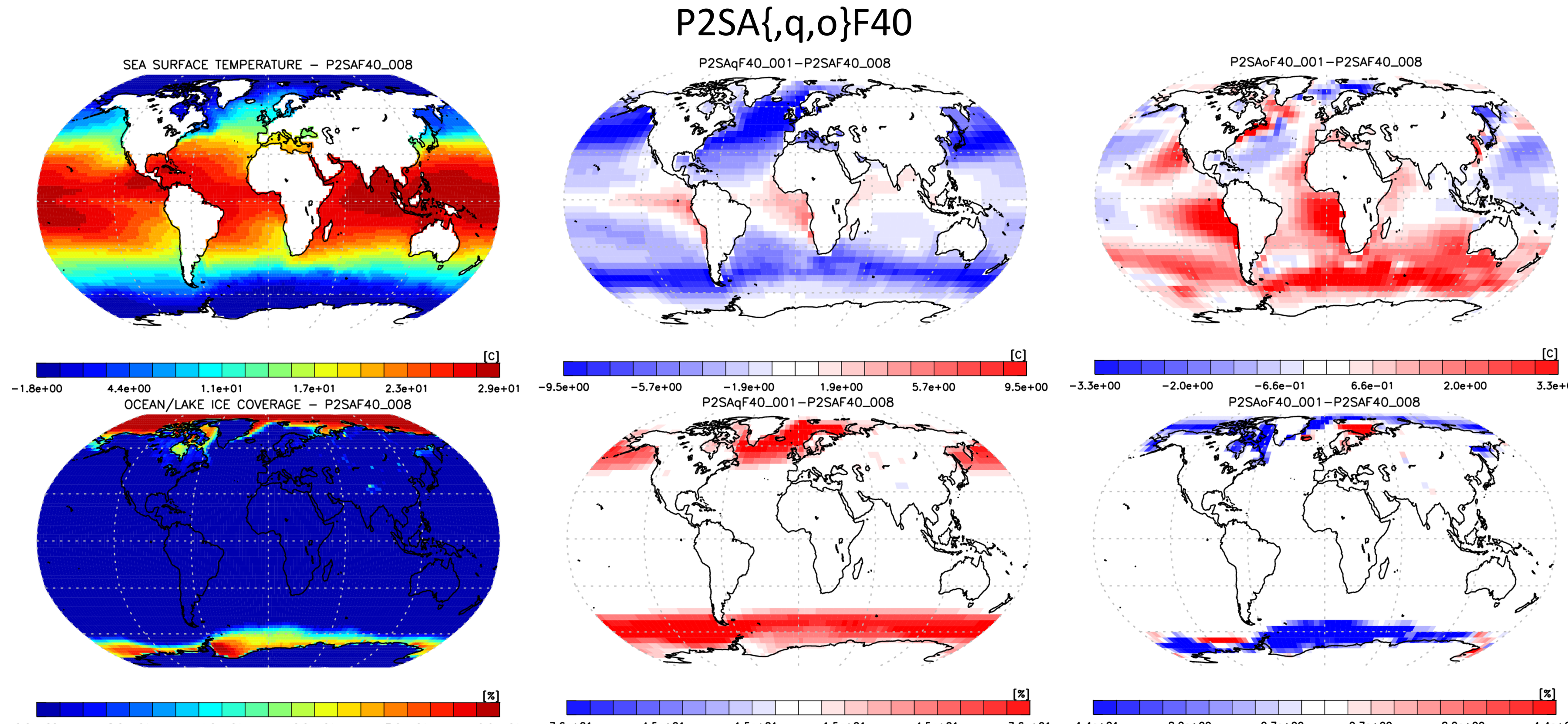


Only the A atmosphere can generate a stratosphere, since it is the only one containing O_3. Upper atmospheric water is also depleted in non-A runs, due to the absence of CH_4 whose chemical oxidation forms H_2O vapor.

Ocean

Same as in ROCKE-3D 1.0, three ocean configurations are available. The first one has no interactive ocean but rather prescribed sea ice extent and sea surface temperature (SST). The second is a zero-qflux ocean, which (contrary to ROCKE-3D 1.0 where we used Earth-like heat fluxes) the heat fluxes throughout the ocean are set to zero. The depth of the ocean is 100 m (was 65 m in ROCKE-3D 1.0). The last configuration is a fully dynamic ocean, similar to what was used in ROCKE-3D 1.0.

P2SA{,q,o}F40



The zero q-flux ocean generates colder SSTs and much more ice around the polar regions, both compared against the prescribed SST and dynamic ocean runs.

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