Future projections of the Asian summer monsoon in Stream-2 integrations of the EU-ENSEMBLES project

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Introduction & models used

Several studies have compared the monsoon response to increased greenhouse gas emissions in CMIP3-class models (*e.g.*, Annamalai *et al.*, 2007; Turner & Slingo, 2009) under idealised 1pctto2x and traditional SRES emissions scenarios. In the EU-ENSEMBLES project, an aggressive mitigation scenario was devised using the IMAGE integrated assessment model. This "E1" scenario aims to stabilize global warming below 2°C (see Johns *et al*., 2011 for more details), consistent with stabilization of atmospheric greenhouse gas concentrations at 450ppmv CO_2-equivalent.

In this *preliminary* study we analyse the mean changes to monsoon rainfall in E1 and SRES-A1B scenario of the ENSEMBLES Stream-2 integrations.

The Stream-2 integrations comprise 10 coupled GCM and Earth System models, although only 9 are studied here, with various combinations of interactive carbon cycle models, aerosol transport or chemistry components and representations of transient land-use change.

Monthly mean data made available on the CERA archive at the World Data Center for Climate, Hamburg were used in this study. Some integrations are repeated in a variety of ensemble members; ensemble means are shown where appropriate. Basic model details are shown in the table.

Model	Atmosphere	Ocean
CNCM33	Arpege-Climat v4.6 (T42L31)	OPA8.1a5 (2°, L31)
DMICM3	Arpege-Climat v4.6 (T63L31)	OPA8.1a5 (2°, L31)
DMIEH5C	ECHAM5-C (T31L19)	MPI-OM (3°, L40)
EGMAM2	ECHAM4 with Middle Atmosphere Model (T30L39)	HOPE-G (T42 with equatorial refinement, L20)
HADCM3C	HADAM3 (N48L19)	HADOM3 with carbon cycle (1.25°, L20)
HADGEM2	HADGEM2-A (N96L38)	HADGEM2-O (1°, L40)
INGVCE	ECHAM5 (T31, L19)	OPA8.2 (2°, L31)
IPCM4v2	LMDZ4_V3_4, (N72L19)	ORCA2 (ipsl_cm4_v2, 2°, L31)
MPEH5C	ECHAM5-C (T31L19)	MPI-OM (3° L40)

Background: global mean temperature response

To examine the global mean response we show global mean surface air temperatures in SRES-A1B and E1 scenarios after Johns *et al*. (2011). The ensemble mean clearly shows that the E1 aggressive mitigation scenario has constrained global mean temperature change slightly below 2°C by the end of the 21st century. The medium-high SRES-A1B scenario shows global mean temperature changes of above 3°C on average.

As noted in Johns *et al*. (2011), the E1 scenario features more rapid cuts in sulphate aerosol forcings that SRES-A1B during the early 21st century, thus reducing their cooling effect on global mean surface temperature. This is reflected in the model ensemble mean curves, where global mean surface temperature change in E1 exceeds that in SRES-A1B between 2000 and 2040.

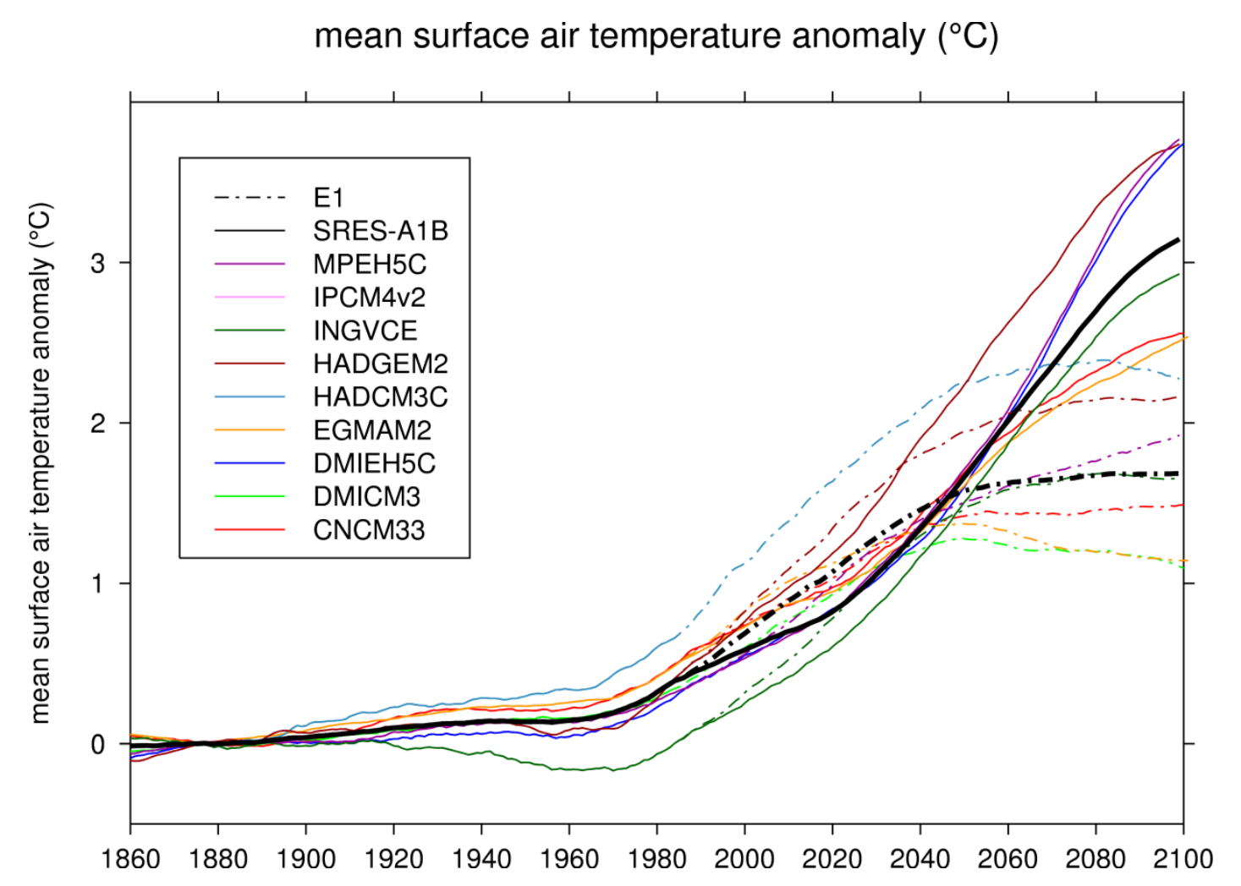

Fig 1: Mean global near surface temperature change in the Stream-2 models for the 20C3M historical simulation followed by SRES-A1B (solid) and E1 (dashed) emissions scenarios. Change is measured with respect to the 1861-1890 pre-industrial period. Each model curve is averaged across all ensemble members. Thick black lines show un-weighted means across all model curves. A 31-year running mean was also applied.

Mean precipitation change

The mean summer monsoon precipitation climatology during the pre-industrial period and end-of-21st century projected changed in E1 and SRES-A1B scenarios are shown in Fig. 2. All models show a reasonable general pattern of monsoon precipitation over the broad Asian monsoon domain although there are notable biases. (See below left for discussion.) See May (2010) for more detailed analysis of the monsoon response in the ECHAM5-C/MPI-OM model combinations.

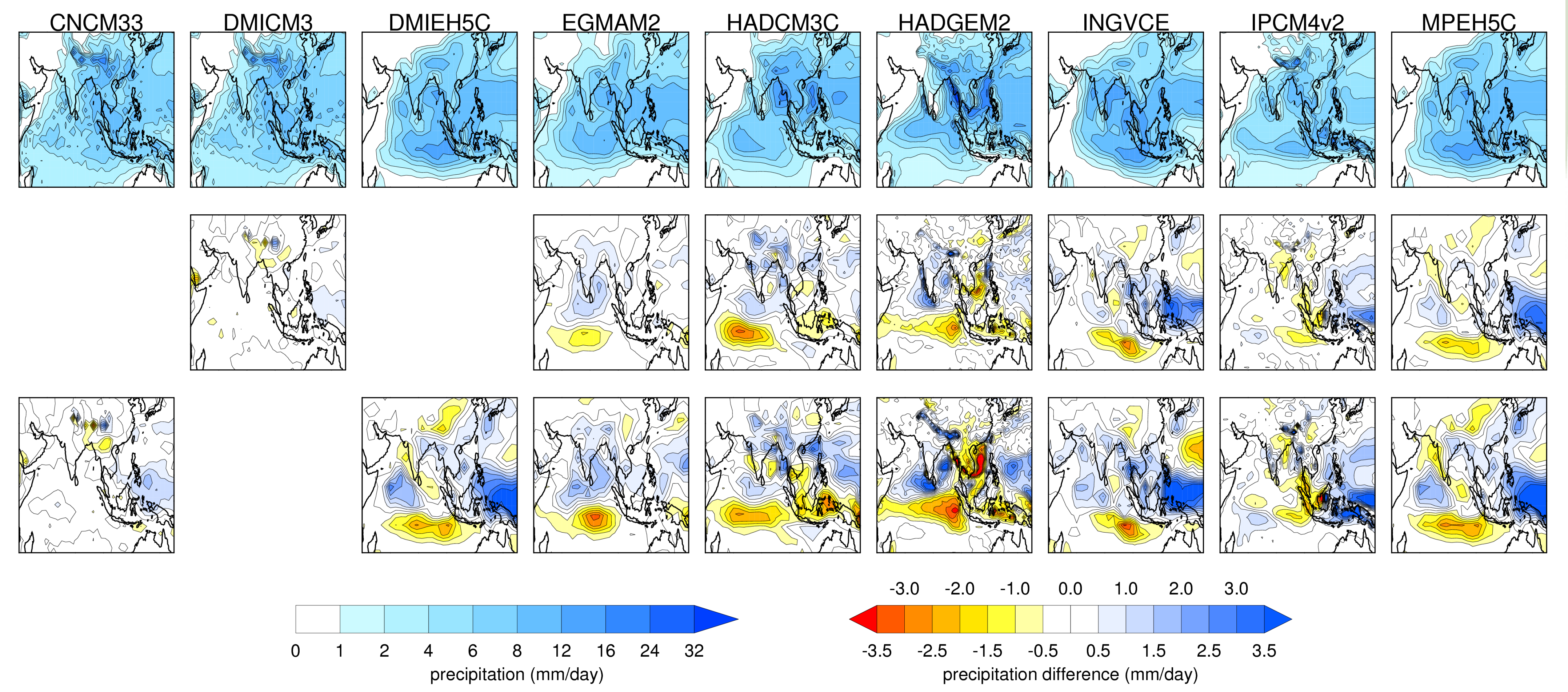

Fig 2: (a) JJAS mean precipitation over the Asian monsoon domain in the ENSEMBLES Stream-2 integrations, averaged over the pre-industrial period (1861-1890); mean precipitation change at the end of the 21st century (2070-2099) in (b) E1 and (c) SRES-A1B emissions scenarios. For some models, both sets of scenario data were not available from CERA.

- Some models perform poorly over orography, particularly with excessive precipitation over the Western Ghats and Himalaya in India (notably in HADGEM2).
- The CNCM33, DMICM3 and HADGEM2 models also show low rainfall climatologies over South Asia (see also Fig. 3a). Most models also show significant wet biases over the western equatorial Indian Ocean.
- Under future projections, SRES-A1B scenario shows generally larger changes than E1. Aside from the CNCM33 and DMICM3 models, all show strong drying signals just south of the equatorial Indian Ocean. Many models also suggest strong increases in the equatorial West Pacific, at the expense of reduced precipitation in the Western North Pacific.

Time-dependent monsoon response

In Fig. 3 we show the time-dependent response of summer monsoon precipitation in the Stream-2 integrations.

- Fig. 3a shows huge variation in the present day simulation of mean rainfall across South Asia, questioning the ability of some models to make reasonable climate projections for the region. Further work is needed to select models according to their ability to simulate the mean monsoon, its seasonal cycle and spectrum of variability (*e.g.*, as for the CMIP3 models in Annamalai *et al.*, 2007 and Sperber & Annamalai, 2008) as well as simulation of mean state SSTs in the tropical Indo-Pacific region (Turner *et al*., 2005).
- Despite these caveats, the un-weighted ensemble mean curves in Fig. 3b show fractional increases in monsoon rainfall by the end of the 21st century of around 7% and 11% in E1 and SRES-A1B scenarios.

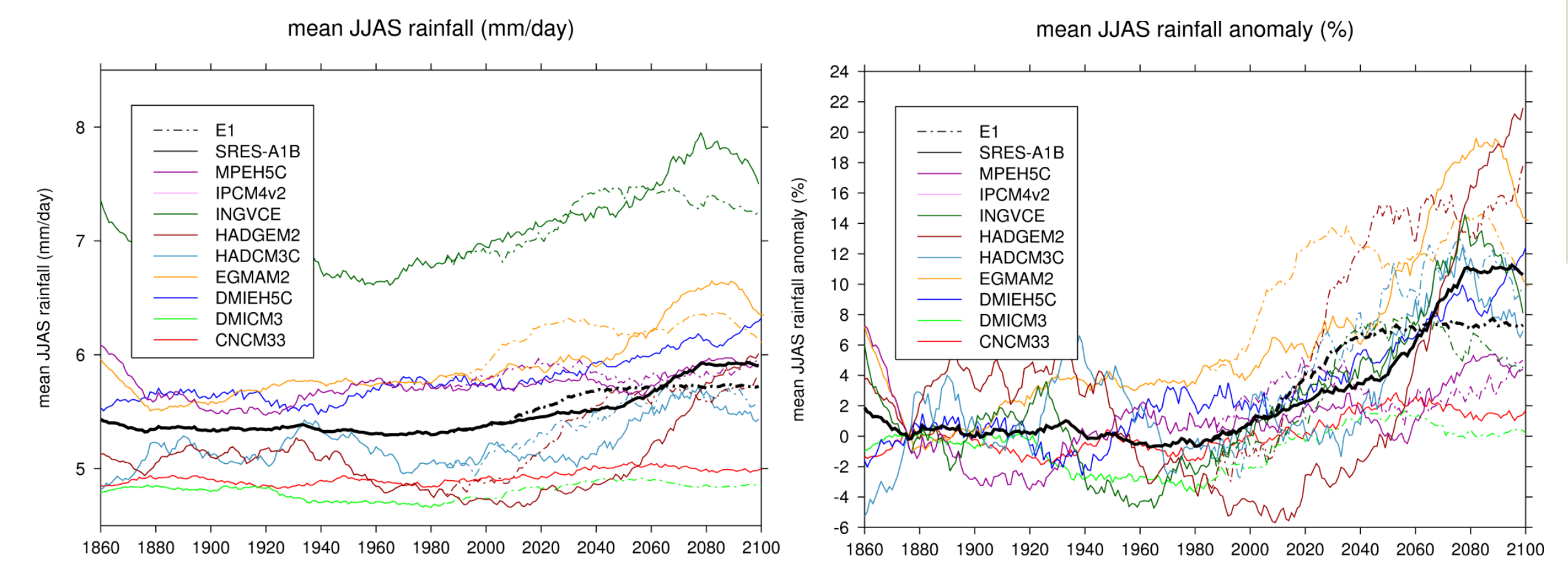

Fig 3: (a) Mean JJAS precipitation over South Asia (60—90°E, 0—30°N) in the Stream-2 models for the 20C3M historical simulation followed by SRES-A1B (solid) and E1 (dashed) emissions scenarios; (b) Fractional precipitation change measured with respect to the 1861-1890 pre-industrial period. Each model curve is averaged across all available ensemble members. Thick black lines show un-weighted means across all model curves. A 31-year running mean was also applied.

- There is clear evidence that the signals in global mean temperature change (Fig. 1) project onto monsoon precipitation, with fractional increases in E1 precipitation between 2010 and around 2060 exceeding those in SRES-A1B. Further work will establish whether this response relates to changes in the large-scale meridional temperature contrast or moisture availability.

Summary and outlook

- **Mean precipitation over South Asia is shown to increase by around 7% (11%) in the aggressive mitigation E1 (SRES-A1B) emissions scenario.**
- **Rapid increases in global mean temperature in the E1 scenario during the early 21st century also project onto South Asian monsoon precipitation such that it exceeds changes in SRES-A1B.**
- **Further analysis is required to determine the role of dynamic (including land-sea contrast) and thermodynamic contributions to precipitation change in the E1 scenario.**
- **Model validation analysis is required to allow suitable weighting of projected future precipitation change over South Asia.**

References Annamalai, H, K Hamilton & KR Sperber (2007) *J Clim* **20**: 1071—1092. // Johns, TC *et al*. (2011) *Clim Dyn* **published online**, doi:10.1007/s00382-011-1005-5 // May, W (2010) *Clim Dyn* **published online**, doi:10.1007/s00382-010-0942-8. // Sperber, KR & H Annamalai (2008) *Clim Dyn* **31**: 345—372. // Turner, AG, PM Inness & JM Slingo (2005) *QJRMS* **131**: 781—804. // Turner, AG & JM Slingo (2009) *Atmos Sci Letts* **10**: 152—168.

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