UNSW AUSTRALIA

ARC CENTRE OF EXCELLENCE FOR CLIMATE SYSTEM SCIENCE

Australian Government
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Influence of an optimal stomatal conductance scheme in ACCESS1.3b under current and future climate

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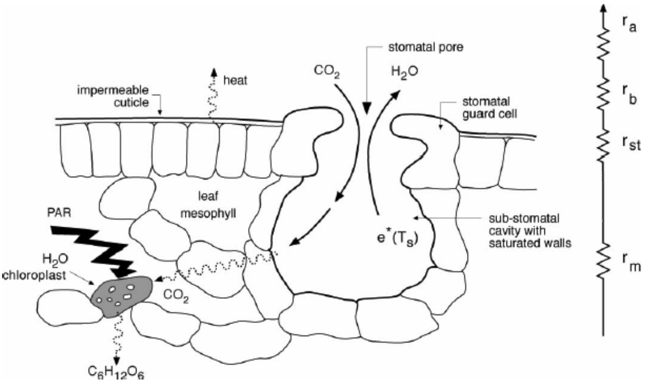
26$^{\mathrm{th}}$ August 2015

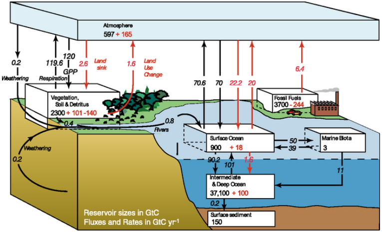
What is Stomatal Conductance (g_s)?



Schematic of a cross-section through a stomate (Pitman 2003)

Pitman A. J. (2003) The evolution of, and revolution in, land surface schemes designed for climate models. *Int. J. Climatol.* 23: 479-510

Why does Stomatal Conductance (g_s) matter?



Schematic of the terrestrial Carbon cycle (from IPCC AR4)

- Vegetation is a net Carbon Sink
  - Carbon sequestration via re-vegetation is an option

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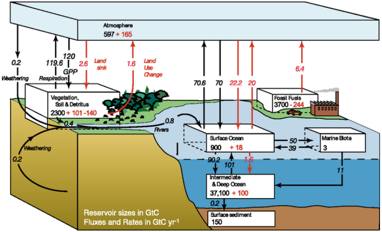

Schematic of the terrestrial Carbon cycle (from IPCC AR4)

- Vegetation is a net Carbon Sink
  - Carbon sequestration via re-vegetation is an option
- Observations show that as atmospheric $CO_2 \uparrow$
  - Stomata act “optimally” to lose less water during photosynthesis
  - g_s schemes need to mimic this “optimal” behaviour accurately

Why does Stomatal Conductance (g_s) matter?

Preferential cloud formation over native vegetation in Western Australia (Lyons 2002)

- g_s controls the amount of H_2O transpired by vegetation
  - Influences the partitioning of available energy into latent and sensible heat
  - Influences the boundary layer

Lyons T. J. (2002) Clouds prefer native vegetation. *Meterol. Atmos. Phys.* 80:131-140

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- g_s controls the amount of H_2O transpired by vegetation
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- Several papers have shown the response of vegetation to $\uparrow CO_2$ via g_s has both regional and global impacts

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Default $\mathrm{g_s}$ parameterisation in CABLE (Leuning et al. (1995)):

$$g_s = g_0 + \frac{a_1 \beta A}{(C_s - \Gamma)(1 + \frac{D}{D_0})} \quad (1)$$

Leuning, R. (1995) A critical appraisal of a combined stomatal-photosynthesis model for $\mathrm{C_3}$ plants. *Plant Cell Environ.* 18, 339-355

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- The fitted parameters g_0 and a_1 do Not vary by PFT but only by photosynthetic pathway (C3 versus C4)
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- But we know from observations that different PFTs differ in water-use strategies
  - New observations of g_s have recently lead to improved schemes

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New g_s scheme in CABLE (Medlyn et al. (2011)):

$$g_s = g_0 + 1.6\left(1 + \frac{g_1\beta}{\sqrt{D}}\right)\frac{A}{C_s} \quad , \quad g_1 \propto \sqrt{\frac{\Gamma^*}{\lambda}} \tag{2}$$

The key point here is:

- Same functional form as Leuning (1995) but:
  - g_1 varies per PFT and derived from 314 species at 56 sites
    - Comprehensive collation of observations of how g_s varies with CO2.
    - Eq. 2 thoroughly tested, including data from elevated CO2 experiments.

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    - Comprehensive collation of observations of how $\mathrm{g_s}$ varies with CO2.
    - Eq. 2 thoroughly tested, including data from elevated CO2 experiments.
  - $\mathrm{g_1}$ parameter provides a physical link to the plant's water-use strategy
    - relates to the marginal cost of water to the plant

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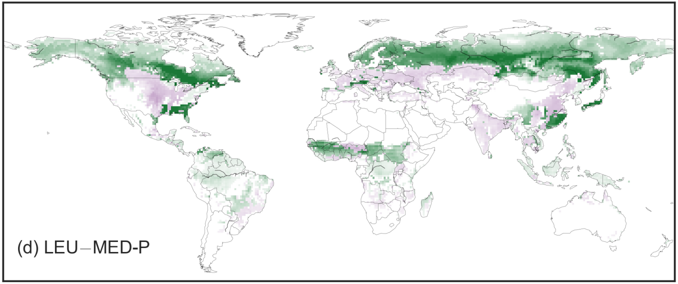
Offline performance - Prescribed Meteorological forcing

- New Scheme results in a ↓ in evapotranspiration over Boreal forests in NH summer by up to 0.8 $\mathrm{mm\ day}^{-1}$



Change in evapotranspiration between the default $\mathrm{g_s}$ scheme (LEU) and the new scheme (MED-P) (De Kauwe and Kala et al. 2015)

De Kauwe and Kala et al., (2015). A test of an optimal stomatal conductance scheme within the CABLE Land Surface Model. *Geosci. Model Dev.*, 8, 431-452

Coupled Land-Atmosphere ACCESS simulations

- AMIP style simulations (prescribed SSTs)
  - Historical simulations, 1950 to 2012 with observed SST
    - Compare with obs
  - RCP8.5 simulations, 2012 to 2100 with CMIP5 SST
    - Influence on future climate projections

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- Two experiments, 5 ensembles each, initialised a year apart
  - Control simulation with default Leuning (1995) g_s scheme (LEU)
  - Actual experiment with new Medlyn et al. (2011) g_s scheme (MED)

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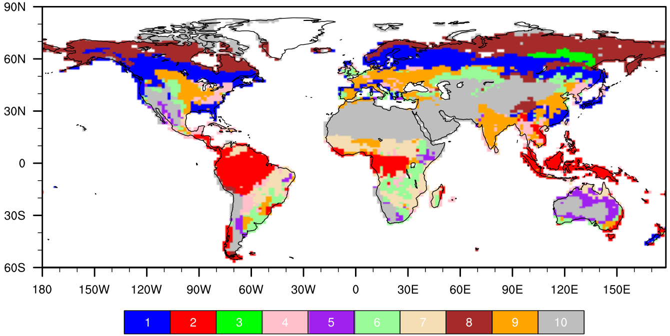
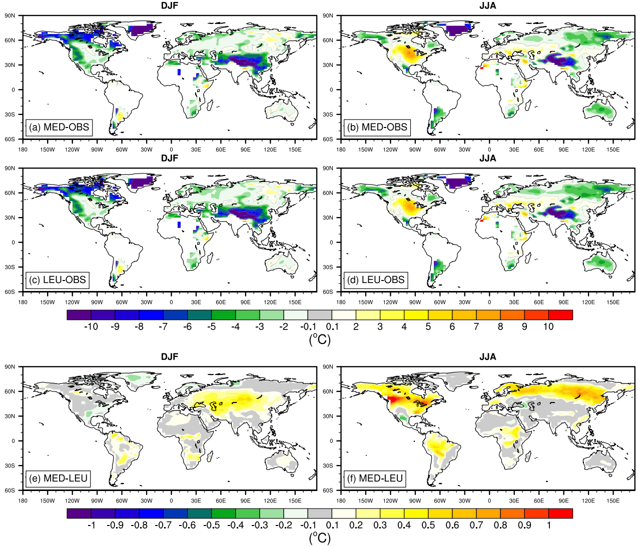
- All results shown will be the ensemble mean

Evaluation under current climate - PFT distribution

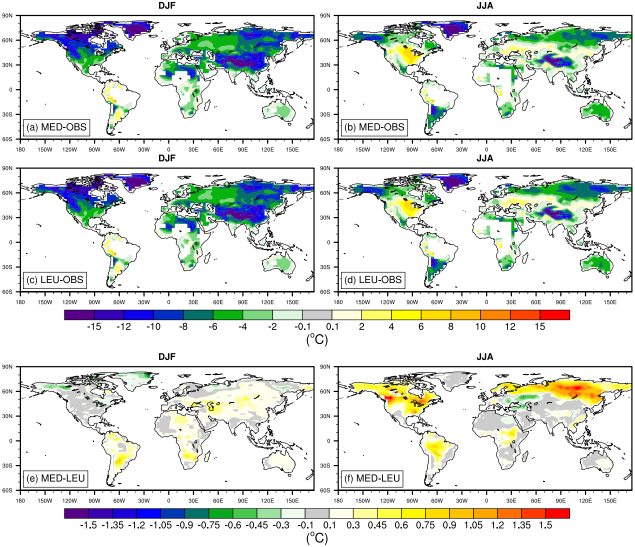


1 - Evergreen needleleaf
2 - Evergreen broadleaf
3 - Deciduous needleleaf
4 - Deciduous broadleaf
5 - Shrub
6 - C3 Grassland
7 - C4 Grassland
8 - Tundra
9 - C3 Cropland
10 - Barren

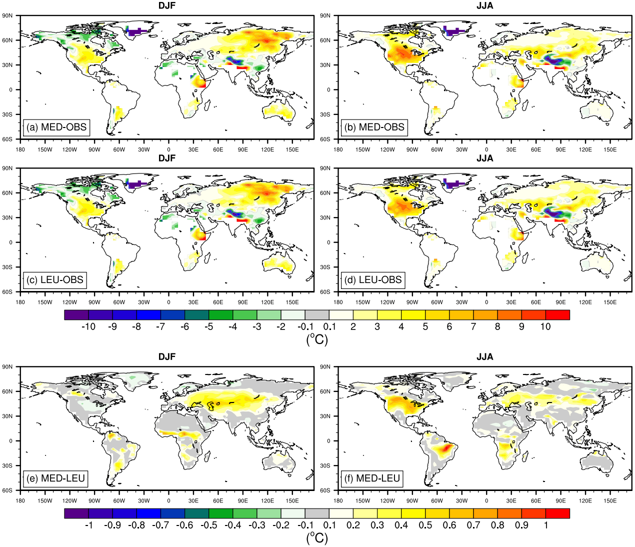
Evaluation under current climate - TMAX



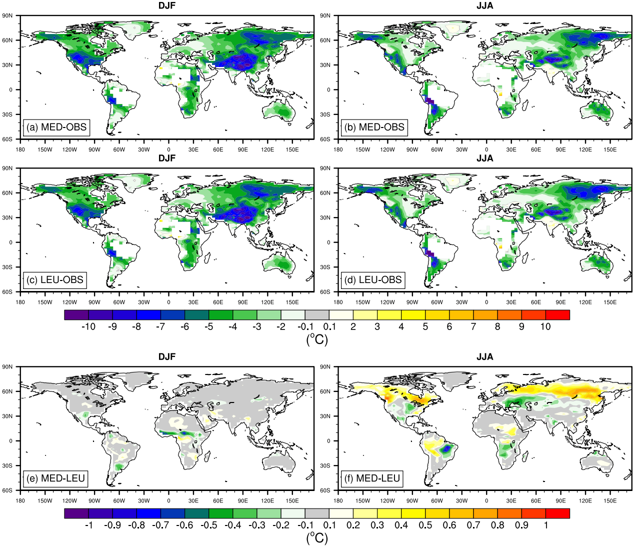
Evaluation under current climate - TXx



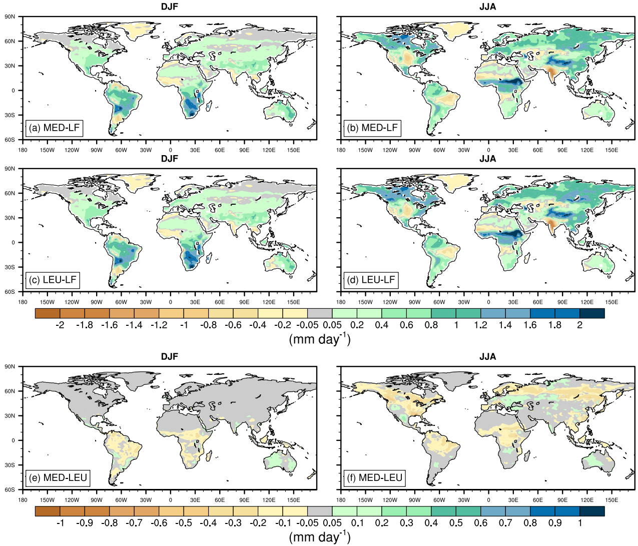
Evaluation under current climate - TMIN



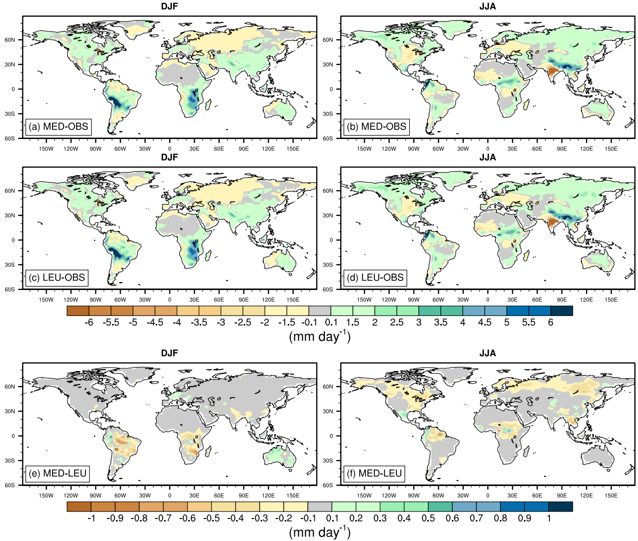
Evaluation under current climate - DTR



Evaluation under current climate - ET/latent heat flux



Evaluation under current climate - PRECIP



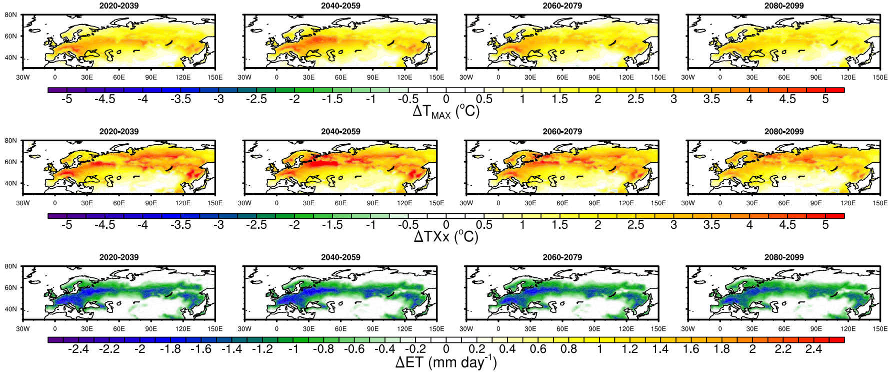
Evaluation under current climate - Summary

- The new scheme reduces latent heat flux over boreal forests using NH summer by 0.5 to 1.0 $\mathrm{mm\ day^{-1}}$

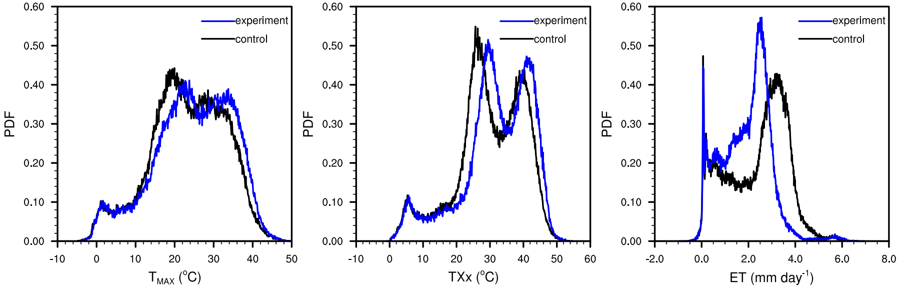
Evaluation under current climate - Summary

- The new scheme reduces latent heat flux over boreal forests using NH summer by 0.5 to 1.0 $\mathrm{mm\ day^{-1}}$
  - Leads to warmer daily maximum and minimum temperatures by up to $1.0^{\circ}\mathrm{C}$
  - Leads to warmer extreme maximum temperatures by up to $1.5^{\circ}\mathrm{C}$
    - We improve the model's climatology by 10-20%

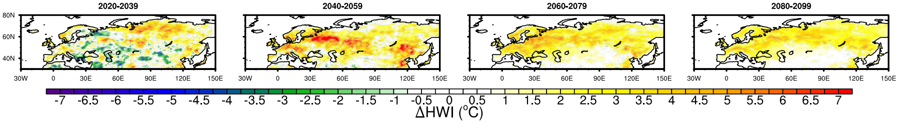
Influence on future climate (RCP8.5) - MED minus LEU



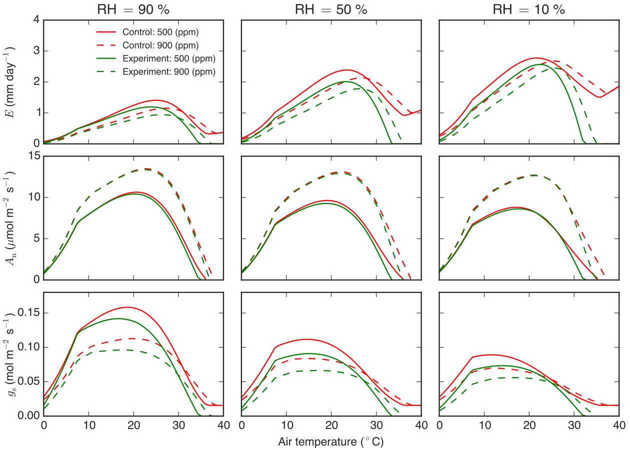
Influence on future climate (RCP8.5)



Influence on future climate (RCP8.5) - MED minus LEU



Damping effect towards 2099



Influence on future climate (RCP8.5) - Summary

- Large increases in warm extremes under RCP8.5 during summer with new scheme over NH up to 4-5$^{\mathrm{o}}\mathrm{C}$!!!
  - Driven by reduction in latent heat flux (and associated increase in sensible heat)

Influence on future climate (RCP8.5) - Summary

- Large increases in warm extremes under RCP8.5 during summer with new scheme over NH up to 4-5°C!!!
  - Driven by reduction in latent heat flux (and associated increase in sensible heat)
- Magnitude of increase, decreases towards 2070-2099
  - At high leaf temperatures, photosynthesis and stomatal conductance (and thus ET) are reduced due to photosynthetic inhibition
    - This minimises the differences in ET between the two models

Take home message

- We introduced a new, more physically grounded g_s scheme in CABLE, based on best available data
  - We tested the scheme at single sites and globally offline
  - This showed improvements in CABLE's ET/latent heat flux simulations

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- We introduced a new, more physically grounded g_s scheme in CABLE, based on best available data
  - We tested the scheme at single sites and globally offline
  - This showed improvements in CABLE's ET/latent heat flux simulations
- We then tested the new scheme coupled within ACCESS
  - We show a general improvement in ACCESS's representation of warm extremes
  - This has serious implications for future climate
    - We are currently under-predicting warm extremes

Take home message

- Historical simulations and evaluation against observations currently under review:
  - Kala et al. (2015) Implementation of an optimal stomatal conductance model in the Australian Community Climate Earth Systems Simulator (ACCESS1.3b), *Geosci. Model. Dev. Discuss., under review*

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- Impacts on future climate submitted to a journal yesterday
  - Watch this space!

Future work on g_s in CABLE/ACCESS

- Link changes in heat fluxes to changes in Carbon fluxes a bit more

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- Suggestion that g_1 parameter varies with climate
- We use prescribed leaf area index
  - Prognostic LAI in CABLE is under-development
    - We expect differences to be larger
- Do we seem the same sign and magnitude of change if the new g_s scheme is implemented in other LSMs which use the Leuning (1995) scheme?

Influence of an optimal stomatal conductance scheme in ACCESS1.3b under current and future climate

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Questions?

Evaluation under current climate - NPP