Influence of Ocean Surface Currents on the Atmospheric Circulation

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How the story begins …

Slab Ocean Model forcing:

```
netcdf pop_frc.gx3v7.110128 {
variables:
float U(time, nj, ni) ;
        U:units = "m/s" ;
        U:long_name = "u ocean current" ;
        U:_FillValue = -999.f ;
float V(time, nj, ni) ;
        V:units = "m/s" ;
        V:long_name = "v ocean current" ;
        V:_FillValue = -999.f ;
```

How the story begins …

Slab Ocean Model forcing:

```
netcdf pop_frc.gx3v7.1
variables:
 float U(time, nj, ni) ;
        U:units = "m/s" ;
        U:long_name = "u c
        U:_FillValue = -99
 float V(time, nj, ni) ;
        V:units = "m/s" ;
        V:long_name = "v c
        V:_FillValue = -99
```

Slab Ocean Model Forcing

David Bailey, Cecile Hannay, Marika Holland, and Richard Neale, NCAR

This document is intended as a brief scientific description or white paper on the Slab Ocean Model formulation in CCSM4.

1. CAM-SOM (i.e. the "old" way)

The method for performing a SOM simulation in the CAM-SOM framework involved calculating the ocean heat transport, or Q-fluxes from an existing CAM simulation with prescribed SST, sea ice extent, and thickness. As with a CAM simulation the intention was to reproduce the *observed* climate, but with the timescale damping effect of a mixed-layer ocean. So-called Q-fluxes were created and used in a SOM simulation in order to recreate the surface flux imbalances seen in the CAM simulation such that the annual cycle of surface temperatures followed that of the prescribed conditions from a CAM simulation. The Q-fluxes were generated from an assumption about the mixed layer depth of the form:

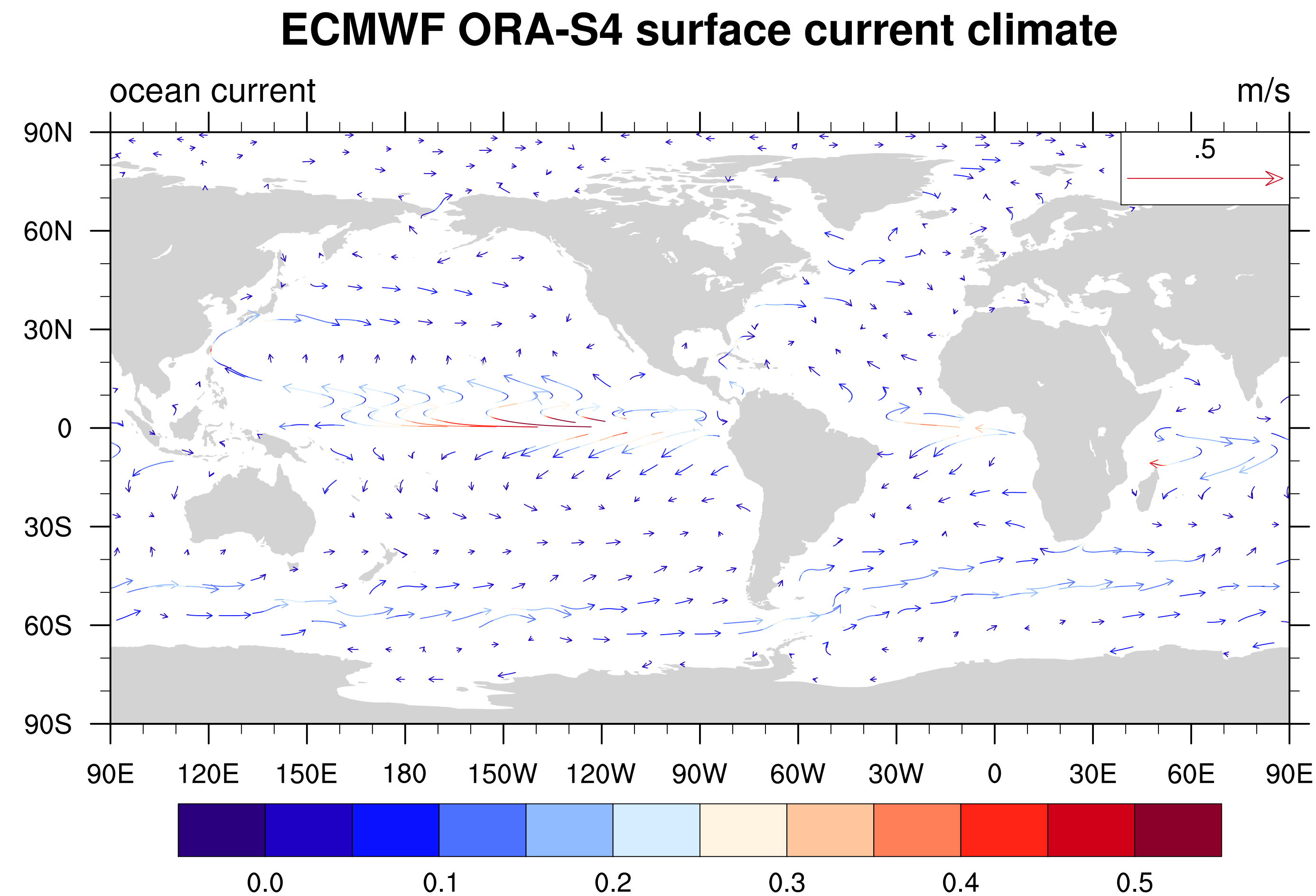
$$Q_{flx} = F_{net} - \rho c_p h_{mix} \frac{dSST}{dt}. \qquad (1)$$

In this case h_{mix} was an estimate of the observed annual mean mixed layer ocean depth, $dSST/dt$ was the change in the sea surface temperature (SST) and F_{net} was the surface net energy balance obtained from a control CAM simulation ($F_{net} = SW - LW - LH - SH$). This method has been the standard procedure for running a SOM and performing climate sensitivity experiments for many years. However, there were a number of drawbacks to this methodology that lead us toward a new approach as we transition the sea-ice model from CSIM to CICE. The greatest difficulty in the above equation was the absence of model information as to the magnitude of fluxes between the ice and ocean. Given the best estimate of the observed monthly variability in ice-fraction an extra flux was added to F_{net} in order to provide a stable ice simulation. This difficulty arose due to the absence of any such information from the CAM run which uses prescribed SST, ice-thickness and ice areal coverage. These additional fluxes were somewhat arbitrary, non-conservative and heavily dependent on the sea-ice model used to determine the thermodynamic evolution of the ice in CAM. The sea-ice model typically used in the CAM-SOM runs was thermodynamic-only and of limited use for polar studies. For these reasons we are opting to switch to a different SOM paradigm.

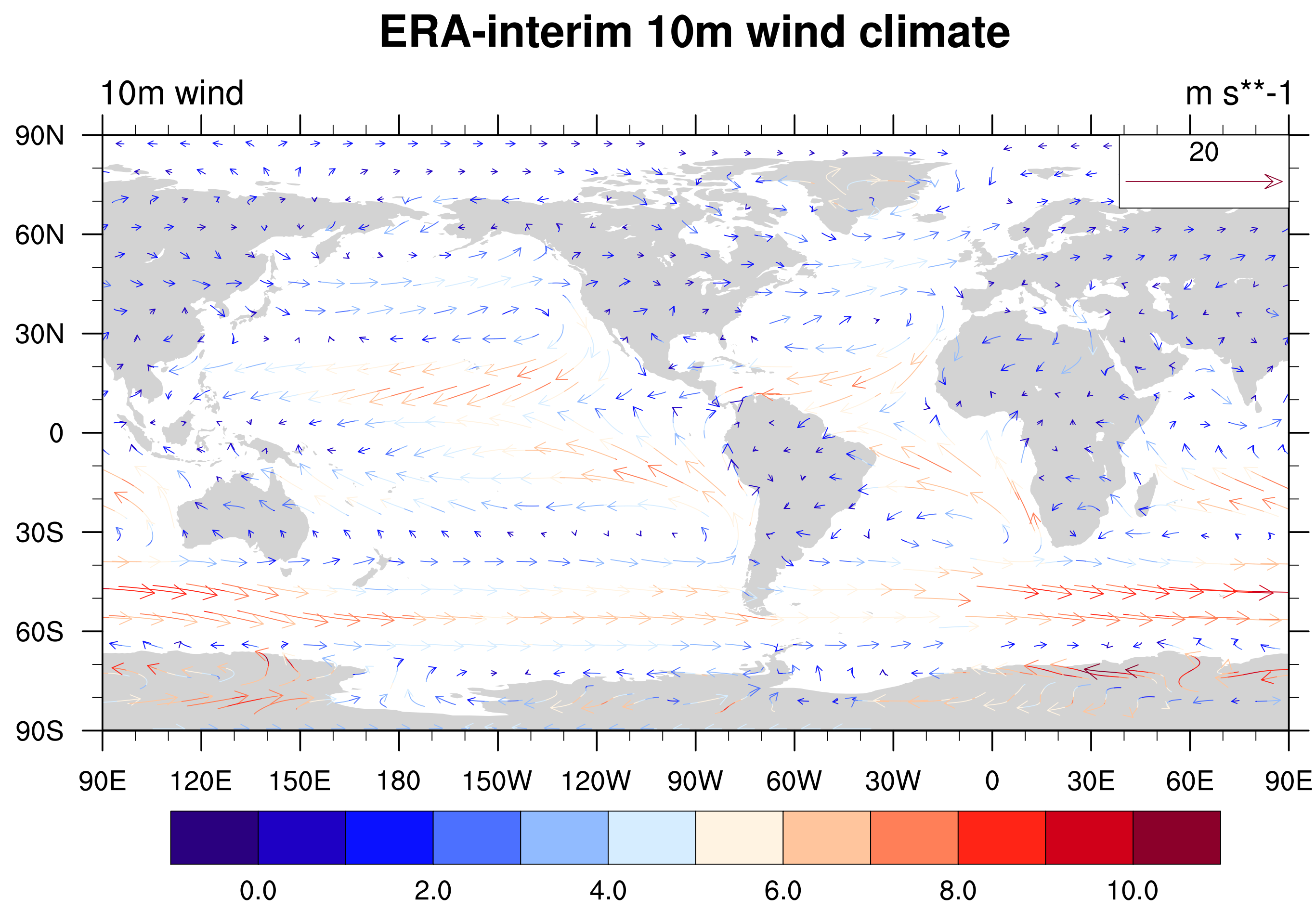
2. CCSM-SOM (i.e. the "new way")

Although the above method aims to reproduce the observed climate mixed layer ocean the Q-fluxes are clearly dominated by the model climate biases. Using the CCSM-SOM method is arguably a more valid approach. Performing a SOM simulation in the CCSM-SOM framework differs from the above methodology in three significant ways: Firstly, the aim is to reproduce the coupled climate of the model as opposed to the observed

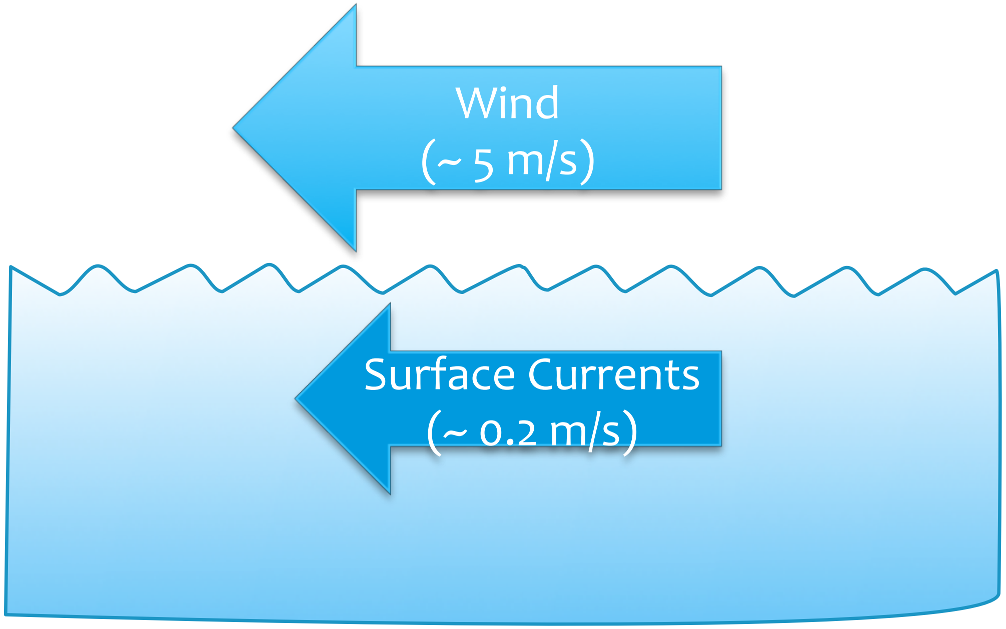
Ocean Surface Currents Climatology



Surface Currents vs. Surface Wind



Surface Currents vs. Surface Wind



Surface currents influence on the atmosphere?

Surface Currents in Model Formulae

CCSM3 CPL6 user-guide:

Momentum (stress), latent heat, and sensible heat across the interface are calculated from bulk formulae and general expressions are :

$$\vec{\tau} = \rho_A \; u^{*2} \; \boxed{\Delta\vec{U} \;\; |\Delta\vec{U}|^{-1}}$$

$$E = \rho_A \; u^{*} \; Q^{*}$$

$$H = \rho_A \; Cp_A \; u^{*} \; \theta^{*}$$

$$L\uparrow = -\sigma \; T^4 \simeq -\epsilon\,\sigma \; T^4 + \alpha^L \; L\downarrow, \tag{16.1}$$

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\end{aligned}
$$

the turbulent velocity scales are :

$$
\begin{aligned}
u^{*} &= CD^{1/2} \; \boxed{|\Delta\vec{U}|} \\
Q^{*} &= CE \; \boxed{|\Delta\vec{U}|} \; (\Delta q) \;\; u^{*-1} \\
\theta^{*} &= CH \; \boxed{|\Delta\vec{U}|} \; (\Delta\theta) \;\; u^{*-1}, \qquad (16.2)
\end{aligned}
$$

At the atmosphere-ocean interface :

$$
\begin{aligned}
\Delta\vec{U} &= \vec{U}_A - \vec{U} \\
\Delta q &= q_A - q \\
\Delta\theta &= \theta_A - T,
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transfer coefficients are themselves functions of u*, Q* and θ*, consequently functions of ΔŨ and surface currents are involved.

Surface Currents in Model Code

CCSM3 CPL6 user-guide:

surface current, $\vec{U}$, is presently assumed to be negligible.

However, in the coupler code where atmosphere/ocean fluxes are computed, role of surface currents are included.

Surface Currents in Model Code

CESM model code:

shr_flux_mod.F90 (SUBROUTINE shr_flux_atmOcn)

```
! PURPOSE:
!    computes atm/ocn surface fluxes
```

```
!--- input arguments --------------------------------
integer(IN),intent(in) ::       nMax  ! data vector length
integer(IN),intent(in) :: mask (nMax) ! ocn domain mask
real(R8)   ,intent(in) :: zbot (nMax) ! atm level height
real(R8)   ,intent(in) :: ubot (nMax) ! atm u wind
real(R8)   ,intent(in) :: vbot (nMax) ! atm v wind
real(R8)   ,intent(in) :: thbot(nMax) ! atm potential T
real(R8)   ,intent(in) :: qbot (nMax) ! atm specific humidity
real(R8)   ,intent(in) :: rbot (nMax) ! atm air density
real(R8)   ,intent(in) :: tbot (nMax) ! atm T
real(R8)   ,intent(in) :: us   (nMax) ! ocn u-velocity
real(R8)   ,intent(in) :: vs   (nMax) ! ocn v-velocity
real(R8)   ,intent(in) :: ts   (nMax) ! ocn temperature
```

```
!--- compute some needed quantities ---
vmag   = max(umin, sqrt( (ubot(n)-us(n))**2 + (vbot(n)-vs(n))**2) )
```

Surface Currents in Model Code

CCSM3 CPL6 user-guide:

Momentum (stress), latent heat, and sensible heat across the interface are calculated from bulk formulae and general expressions are :

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\tag{16.1}
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the turbulent velocity scales are :

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$$

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Surface Currents in Model Code

CESM model code:

docn_comp_mod.F90 (Data ocean e.g. **AMIP** type run)

```
case('SSTDATA')
   lsize = mct_avect_lsize(o2x)
   do n = 1,lsize
      o2x%rAttr(kt   ,n) = o2x%rAttr(kt,n) + TkFrz
      o2x%rAttr(ks   ,n) = ocnsalt
      o2x%rAttr(ku   ,n) = 0.0_r8
      o2x%rAttr(kv   ,n) = 0.0_r8
      o2x%rAttr(kdhdx,n) = 0.0_r8
      o2x%rAttr(kdhdy,n) = 0.0_r8
      o2x%rAttr(kq   ,n) = 0.0_r8
   enddo
```

For case('SOM') ocean surface currents are not set to zero.

Surface Currents Experiment -- Model Configuration

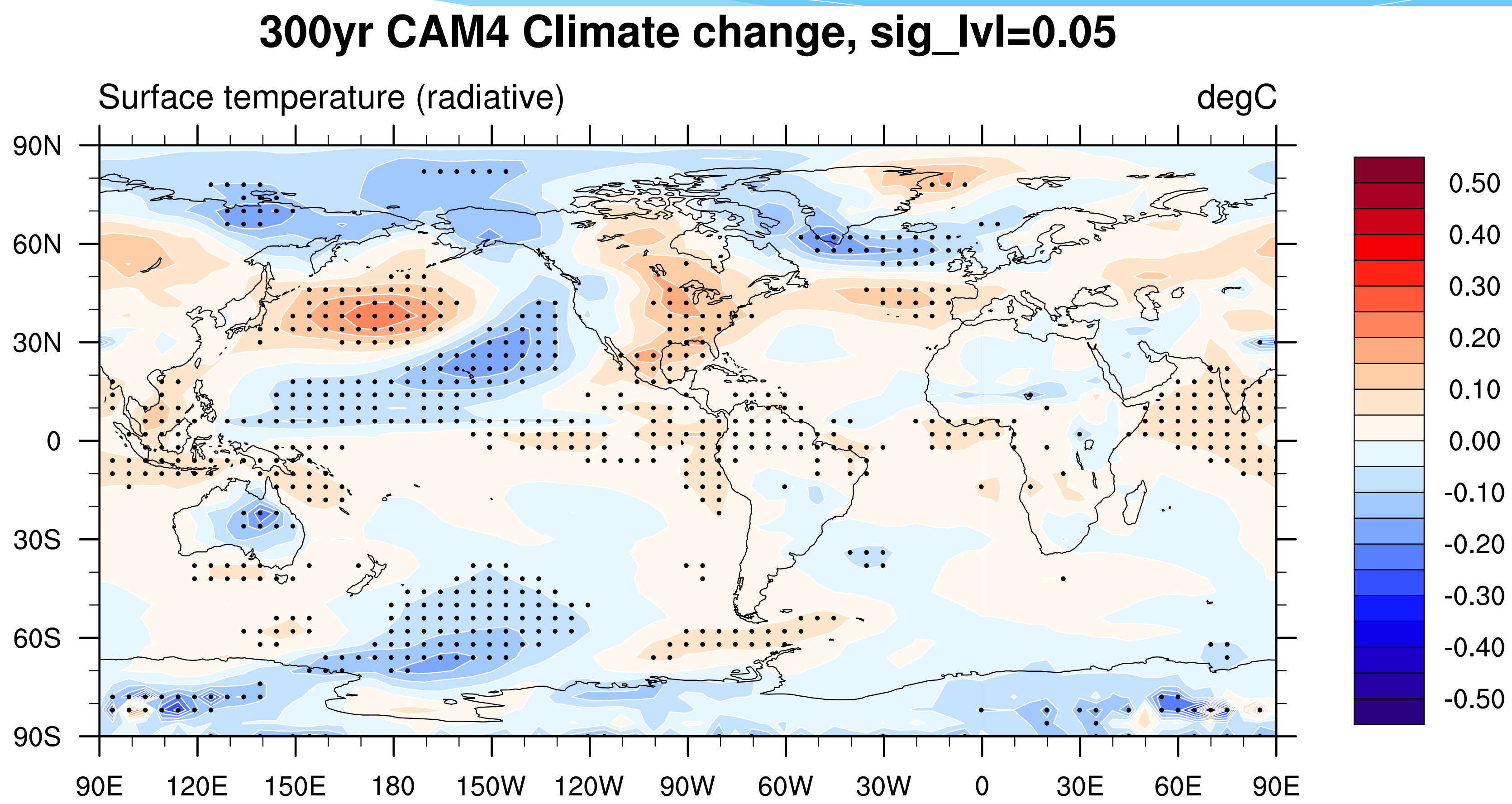
CESM 1_2_2

Experiment Name	SOM_Cur	SOM_Cur0	AMIP_Cur	AMIP_Cur0
Coupling	Yes	Yes	No	No
Compset	CAM + SOM (E)	CAM + SOM (E)	CAM + SOM* (E)	CAM (F)
Prescribed Currents	observed	0	observed	0

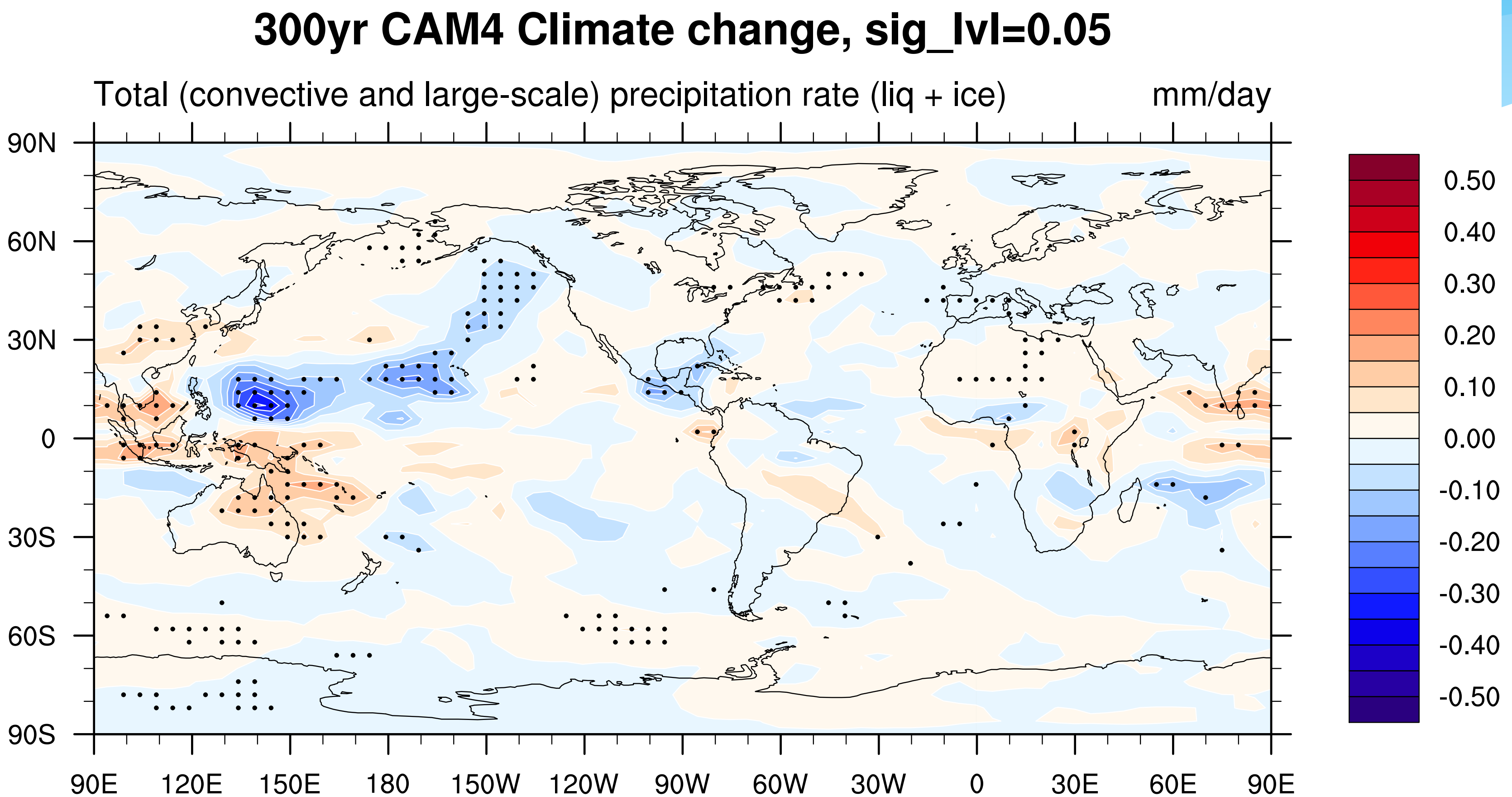
SOM* : overwrite SOM SST with prescribed SST

For CAM4, resolution is f45_g37 (~ 4° atm, 3° ocn)
For CAM5, resolution is f19_g16 (~ 2° atm, 1° ocn)

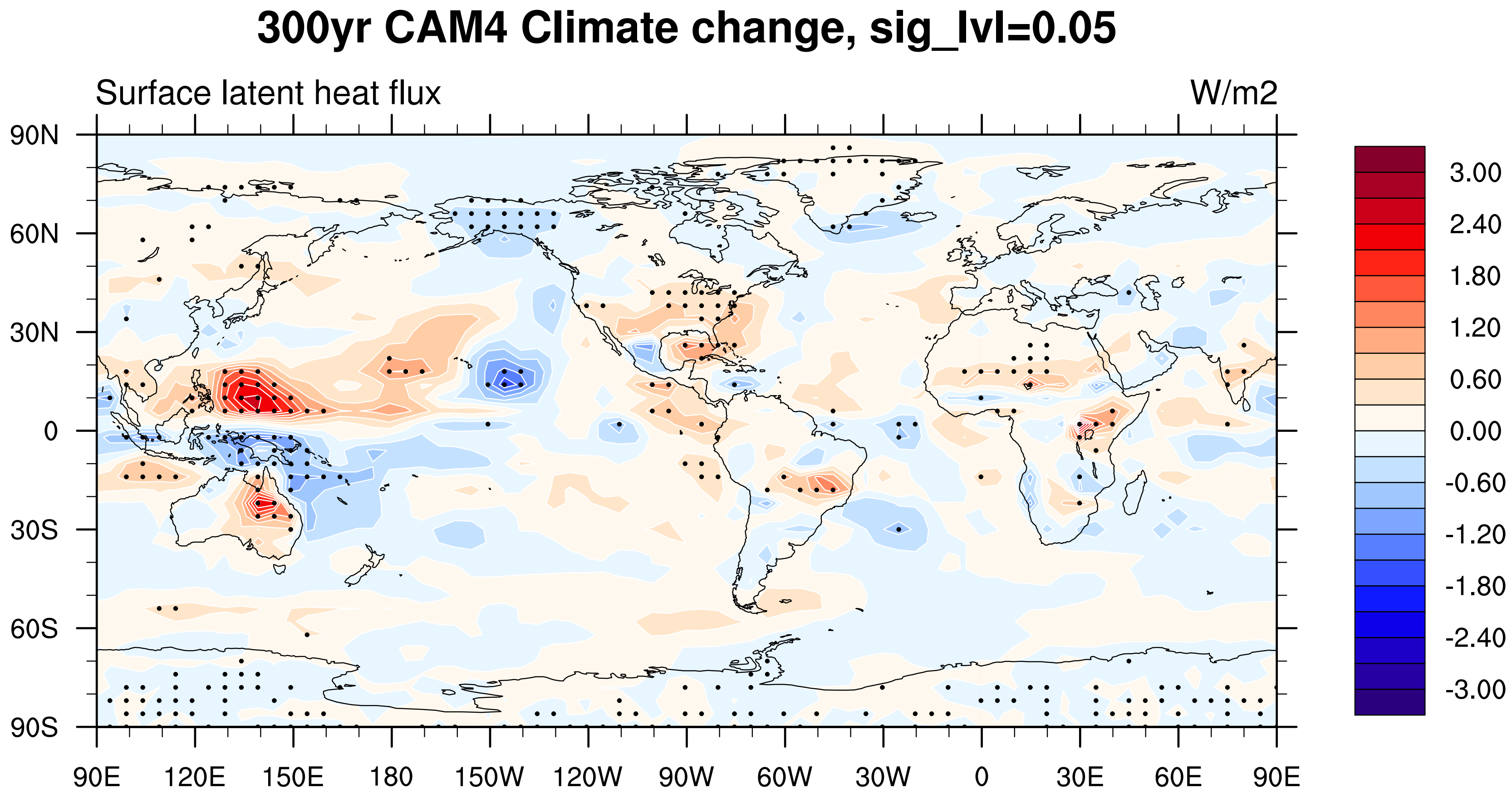
Surface Currents Experiment Results
-- Surface Temperature Changes (coupled)



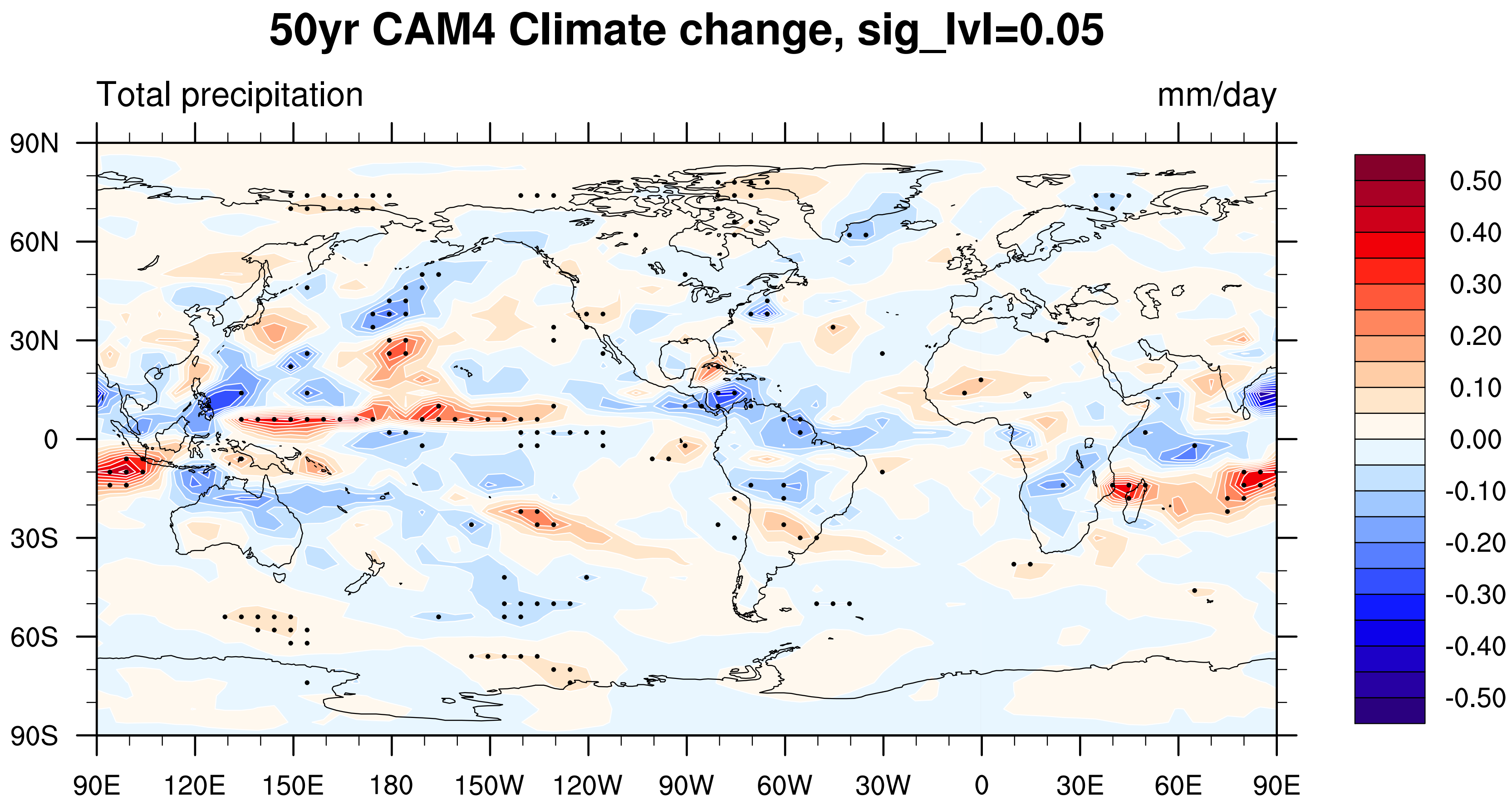
Surface Currents Experiment Results -- Precipitation Changes (coupled)



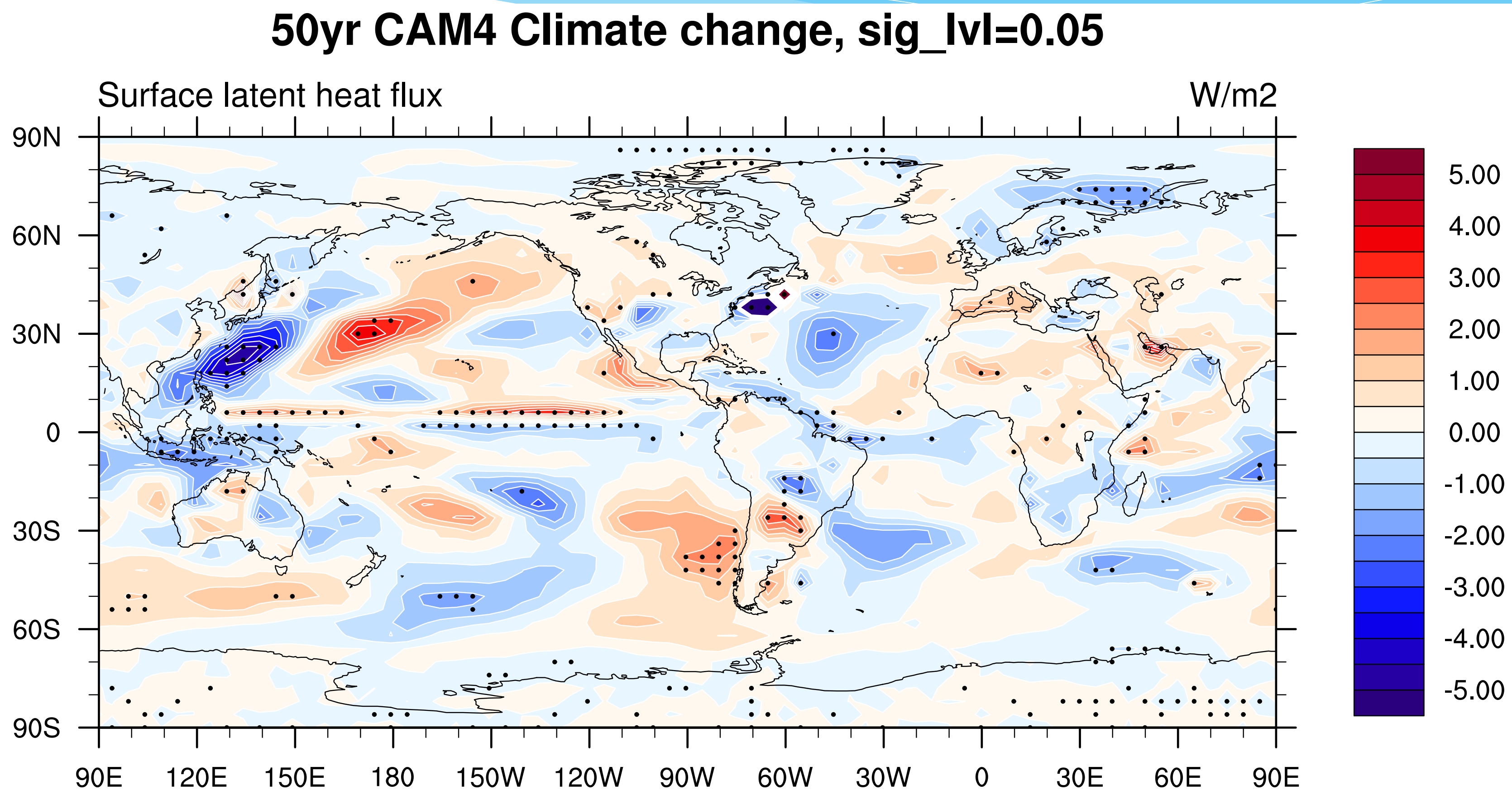
Surface Currents Experiment Results
-- Surface Latent Heat Flux Changes (couple



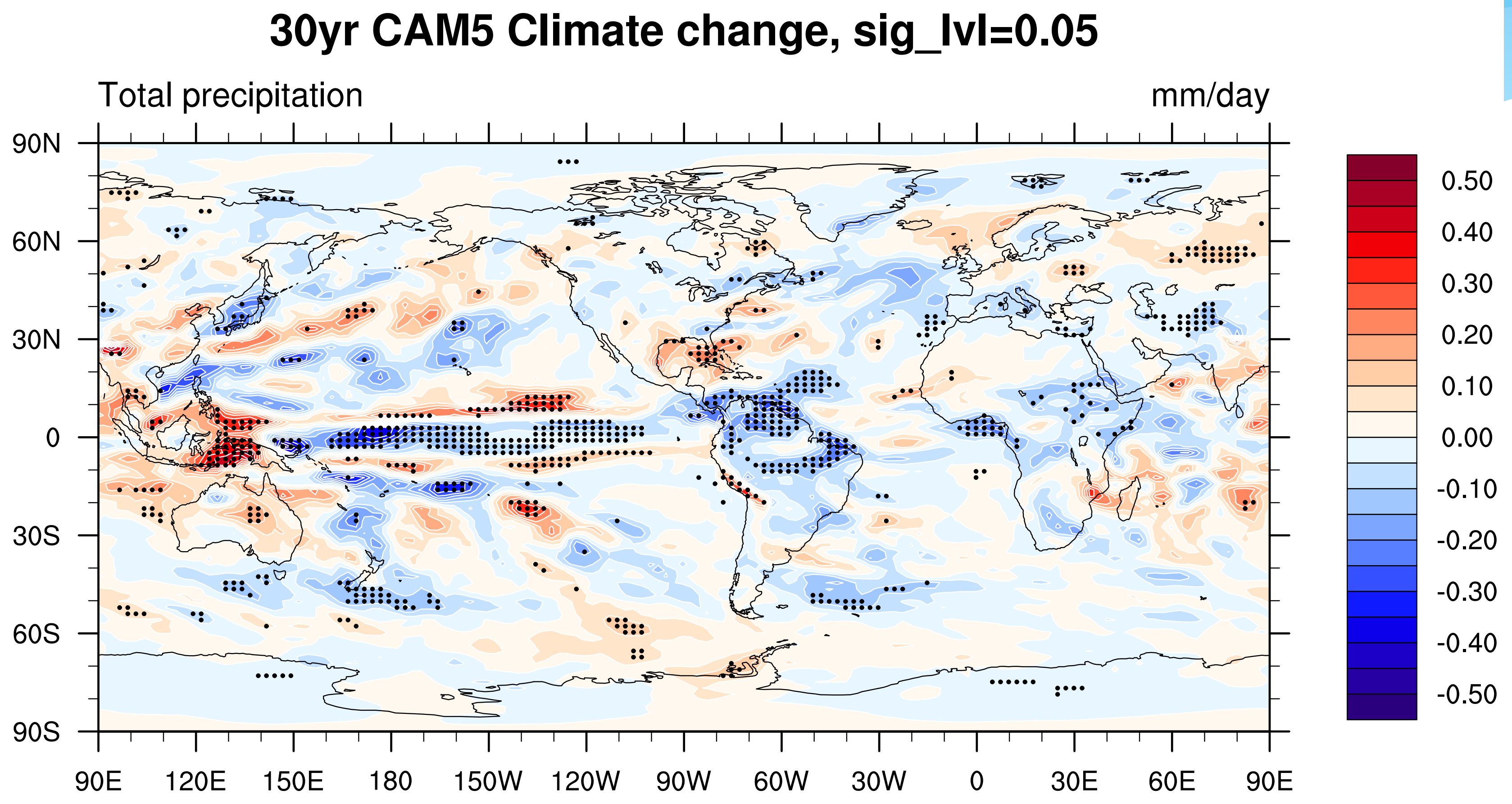
Surface Currents Experiment Results -- Precipitation Changes (AMIP)



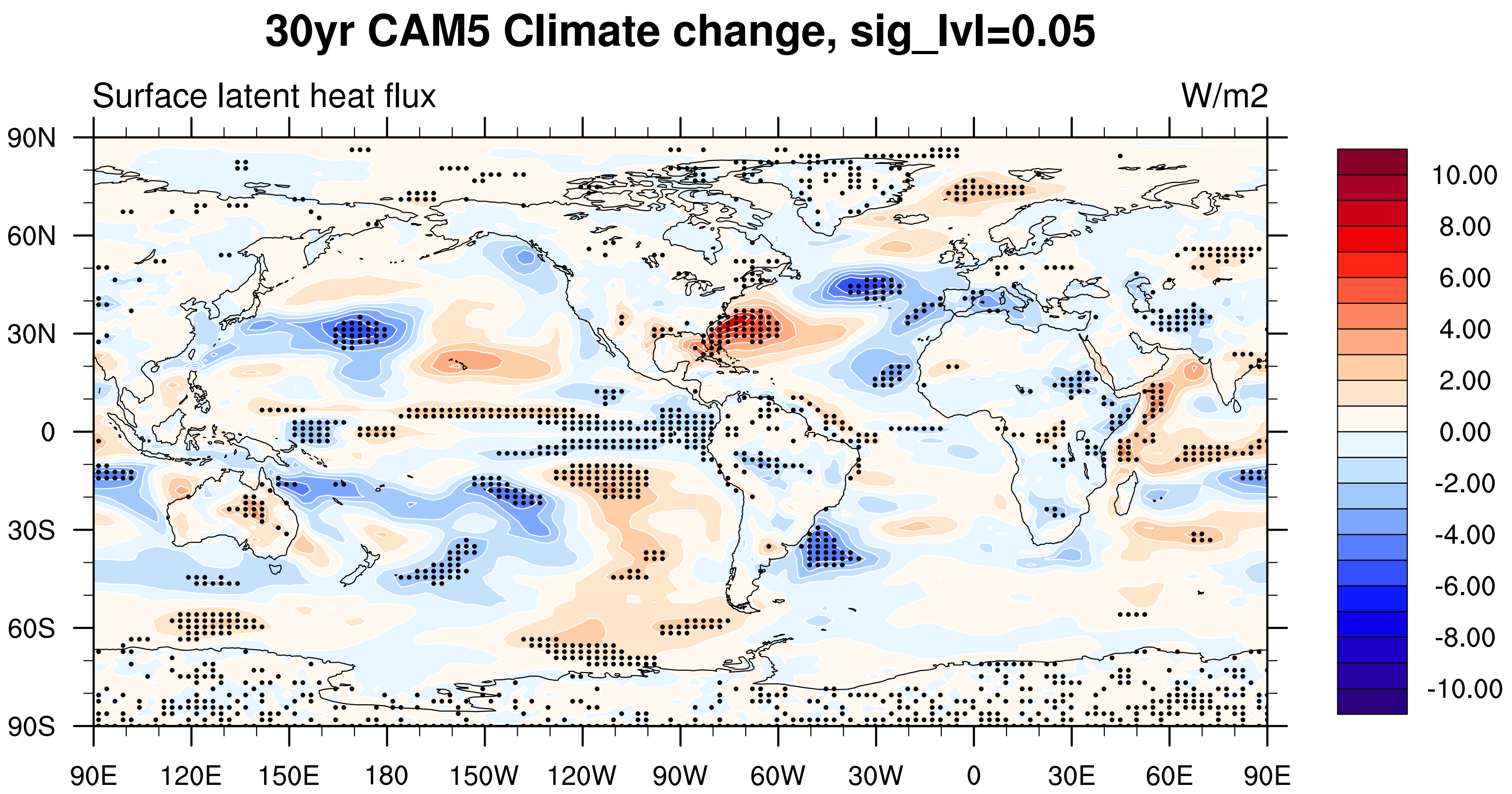
Surface Currents Experiment Results -- Surface Latent Heat Flux Changes (AMIP)



Surface Currents Experiment Results -- Precipitation Changes (AMIP CAM5)



Surface Currents Experiment Results -- Surface Latent Heat Flux Changes (AMIP)



Conclusion

The inclusion of the surface ocean currents could

1. affect the atmospheric surface stress, the friction velocity, and the boundary layer stability parameter;
2. ultimately influencing the surface transfer and vertical mixing coefficients;
3. lead to systematic changes in the surface sensible and latent heat fluxes, affects atmosphere circulation.

Boundary condition for conventional AMIP/coupled model setting differs when includes surface currents