BRINGING REALISTIC AEROSOL EMISSIONS AND INITIALIZATION TO IMPROVE CLOUD CONDENSATION NUCLEI AND ICE NUCLEI REPRESENTATION IN MPAS FORECASTS

Laura D. Fowler[1], Mary C. Barth[1,2], Michael G. Duda[1], and Duseong Jo[2]

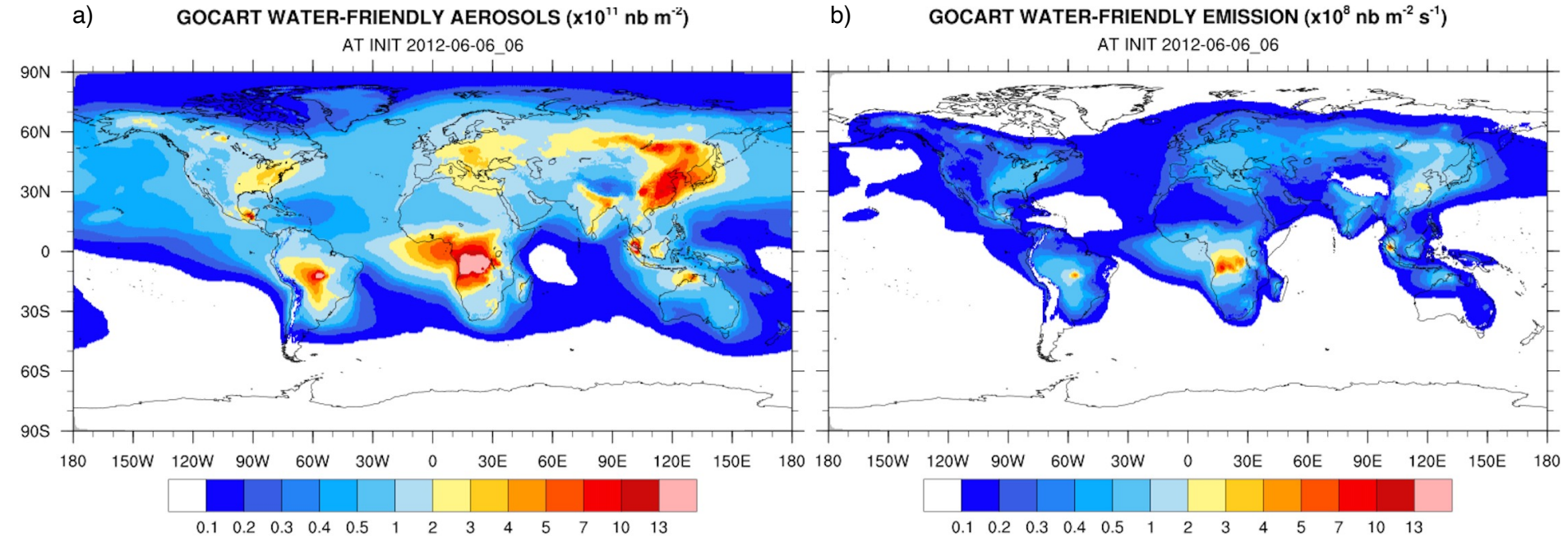
[1]Mesoscale and Microscale Meteorological Laboratory
[2]Atmospheric Chemistry Observations & Modeling
National Center for Atmospheric Research, Boulder, Colorado. USA.

2022 JOINT WRF/MPAS USERS' WORKSHOP (6th-9th June 2022), Boulder, Colorado

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

The *aerosol-aware* Thompson parameterization of cloud microphysics (Thompson and Eidhammer, 2014)

- Cloud microphysics processes follow Thompson et al. (2004, 2008).
- The aerosol-aware option includes the activation of cloud condensate nuclei (CCN) and ice nuclei (IN).
- The aerosol-aware option groups aerosols in two categories: "water-friendly" hygroscopic aerosols for cloud droplet nucleation, and "ice-friendly" non hygroscopic aerosols for cloud ice activation.
  - "Water-friendly" aerosols include organic carbon, sulfates, sea salts, and dust mass less than 0.5 μm. Cloud droplet activation follows Saleeby and Cotton (2004, 2008). Parameterized surface emission.
  - "Ice-friendly" aerosols includes non hygroscopic dust mass larger than 0.5 μm. Cloud ice activation follows Demott et al. (2010) and Phillips et al. (2008). Dust emission needs to be linked to a dust model.
- Global distributions of monthly-mean "water-friendly" and "ice-friendly" aerosols are based on the 2001-2007 GOCART simulations (Ginoux et al. 2001).



Motivations

1. Implement physically-based aerosols-clouds interactions that includes

   - Surface emissions of anthropogenic aerosols from the monthly-mean CAMS inventory.
   - Initialization of aerosols using CAM-Chem outputs.
   - Parameterized emissions of natural aerosols (sea-salts, dust) from the GOCART bulk aerosol model.

2.Add links between physics and chemistry.

PHYSICS

SCALE-AWARE GRELL-FREITAS CONVECTIVE SCHEME

- convective transport of aerosols and passive tracers, including wet scavenging.

THOMPSON AEROSOL-AWARE CLOUD MICROPHYSICS SCHEME

- nucleation of “water-friendly” aerosols to cloud water number.
- nucleation of “ice-friendly” aerosols to cloud ice number.

EDMF MYNN PBL SCHEME

- PBL and free-atmosphere mixing of aerosols and passive tracers.

PHYSICS

SCALE-AWARE GRELL-FREITAS CONVECTIVE SCHEME

- convective transport of aerosols and passive tracers, including wet scavenging.

THOMPSON AEROSOL-AWARE CLOUD MICROPHYSICS SCHEME

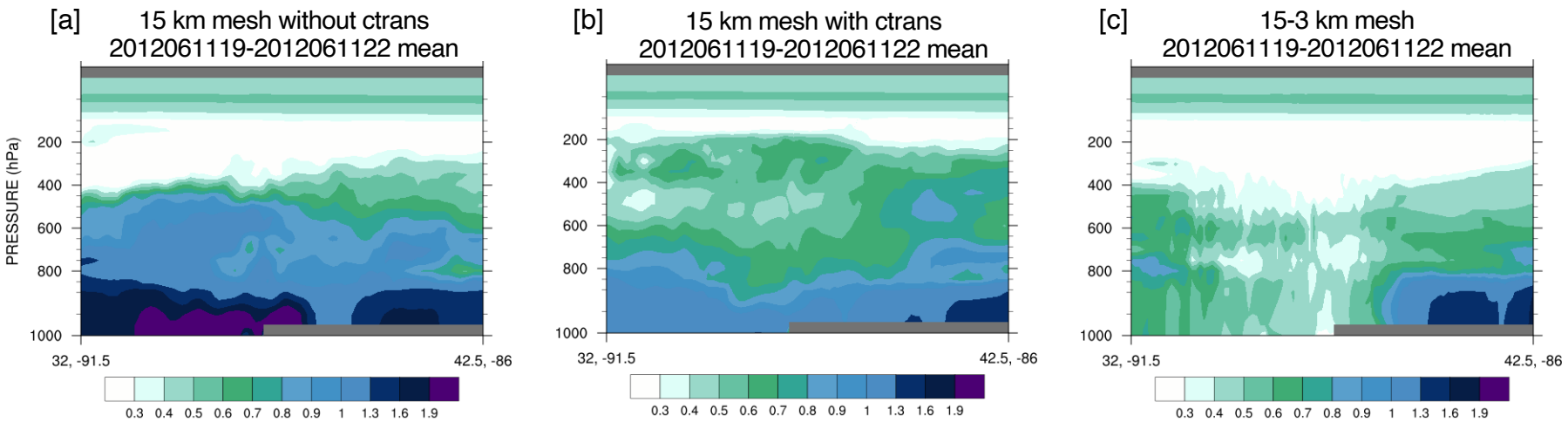
- nucleation of “water-friendly” aerosols to cloud water number.
- nucleation of “ice-friendly” aerosols to cloud ice number

EDMF MYNN PBL SCHEME

- PBL and free-atmosphere mixing of aerosols and passive tracers.

11th June 2012 Mesoscale Convective System observed during the DC3 campaign

Transect of “water-friendly” aerosols (x10^9 nb kg^{-1}) at the peak of the MCS (no surface emissions)



no convective transport | implicit convective transport | explicit convective transport

CHEMISTRY

GOCART-BASED SCHEME

- update anthropogenic, sea-salts, and dust aerosols using realistic surface emissions.

PHYSICS

SCALE-AWARE GRELL-FREITAS CONVECTIVE SCHEME

- convective transport of aerosols and passive tracers, including wet scavenging.

THOMPSON AEROSOL-AWARE CLOUD MICROPHYSICS SCHEME

- nucleation of “water-friendly” aerosols to cloud water number.
- nucleation of “ice-friendly” aerosols to cloud ice number

EDMF MYNN PBL SCHEME

- PBL and free-atmosphere mixing of aerosols and passive tracers.

SURFACE EMISSIONS

CAMS MONTHLY-MEAN INVENTORY

- update anthropogenic organic carbon, and sulfates.

CAMS: Copernicus Atmosphere Monitoring Service

GOCART-BASED SCHEME

- update sea-salt, dust aerosols using the GOCART emission schemes.

INITIAL CONDITIONS

CAM-Chem/MAM4

- Initialize anthropogenic, sea-salt, and dust aerosols

MAM4: Modal Aerosol Module (v4)

CHEMISTRY

GOCART-BASED SCHEME

- update anthropogenic, sea-salts, and dust aerosols using realistic surface emissions.

PHYSICS

SCALE-AWARE GRELL-FREITAS CONVECTIVE SCHEME

- convective transport of aerosols and passive tracers, including wet scavenging.

THOMPSON AEROSOL-AWARE CLOUD MICROPHYSICS SCHEME

- nucleation of “water-friendly” aerosols to cloud water number.
- nucleation of “ice-friendly” aerosols to cloud ice number

EDMF MYNN PBL SCHEME

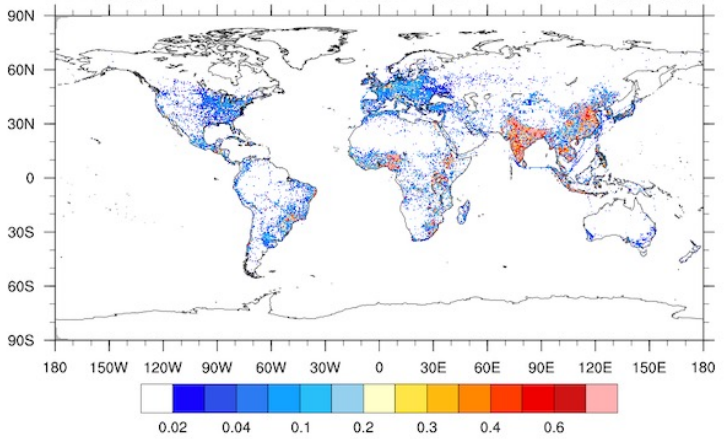
- PBL and free-atmosphere mixing of aerosols and passive tracers.

SURFACE EMISSIONS OF ANTHROPOGENIC AEROSOLS (OC AND SO2)

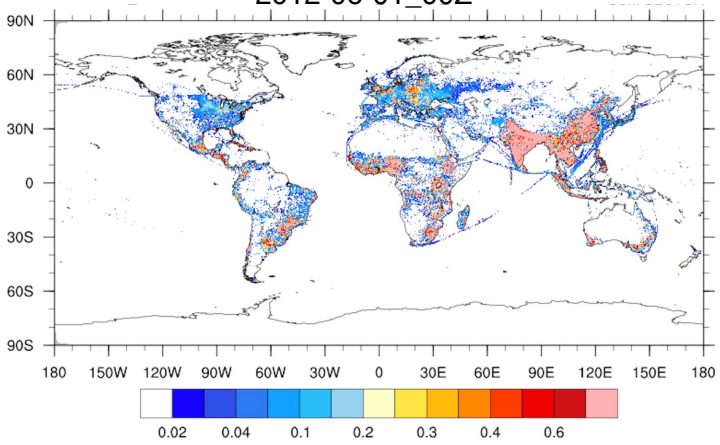
Monthly-mean emissions of anthropogenic aerosols (OC, SO2) from the Copernicus Atmosphere Monitoring Service (CAMS) are interpolated to MPAS meshes with the python-based ESMF-regridding script developed by Duseong Jo.

- Read as an input stream.
- Interpolation of the monthly-mean surface emissions to the initial start time.

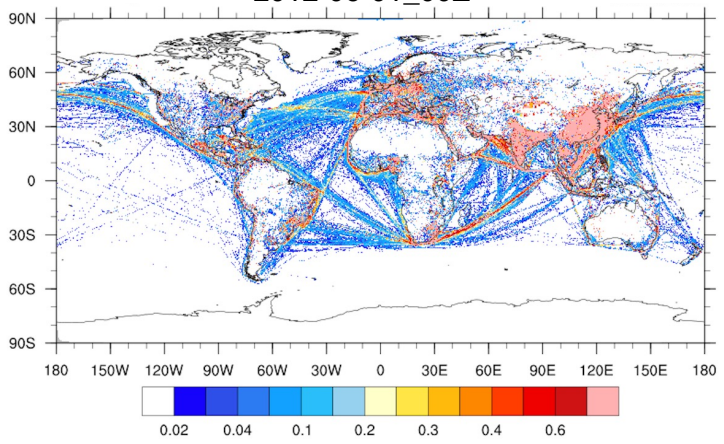
a) Surface emission of BC ($x10^{-11}$ kg m^{-2} s^{-1})
2012-06-01_00Z



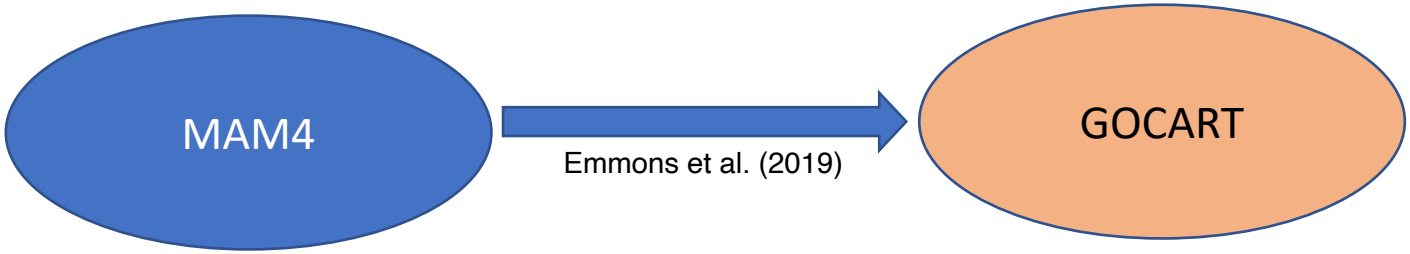
b) Surface emission of OC ($x10^{-11}$ kg m^{-2} s^{-1})
2012-06-01_00Z



c) Surface emission of SO2 ($x10^{-11}$ kg m^{-2} s^{-1})
2012-06-01_00Z



MAPPING OF CAM-Chem/MAM4 AEROSOLS TO THOMPSON AEROSOLS: STEP 1



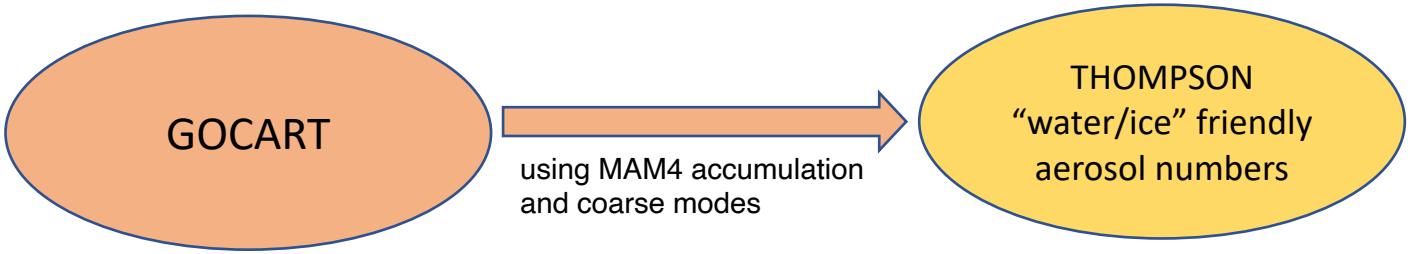
- Primary carbon mode [0.058μm-0.27μm]
- Accumulation mode [0.058μm-0.27μm]
- Aitken mode [0.015μm-0.053μm]
- Coarse mode [0.8μm-3.65μm]

- Hydrophobic OC
- Hydrophilic OC
- Sulfates
- Four bins for sea-salts:
  - [0.1μm-0.5μm]
  - [0.5μm-1.5μm]
  - [1.5μm-5.0μm]
  - [5.0μm-10.μm] = 0
- Five bins for dust
  - [0.1μm-1.0μm]
  - [1.0μm-1.8μm]
  - [1.8μm-3.0μm]
  - [3.0μm-6.0μm] = 0
  - [6.0μm-10.μm] = 0

STEP 1:

1. retain the composition of “water-friendly” and “ice-friendly” aerosols first proposed by Thompson and Eidhammer (2014).
2. retain the simple parameterization of natural aerosols provided by the bulk GOCART aerosol model.

MAPPING OF CAM-Chem/MAM4 AEROSOLS TO THOMPSON AEROSOLS: STEP 2



- Hydrophobic OC
- Hydrophilic OC
- Sulfates
- Four bins for sea-salts:
  - [0.1μm-0.5μm]
  - [0.5μm-1.5μm]
  - [1.5μm-5.0μm]
  - [5.0μm-10.μm] = 0
- Five bins for dust
  - [0.1μm-1.0μm]
  - [1.0μm-1.8μm]
  - [1.8μm-3.0μm]
  - [3.0μm-6.0μm] = 0
  - [6.0μm-10.μm] = 0

Water-friendly (hygroscopic) aerosols

The number concentration of nwfa is similar to that of the MAM4 accumulation mode.

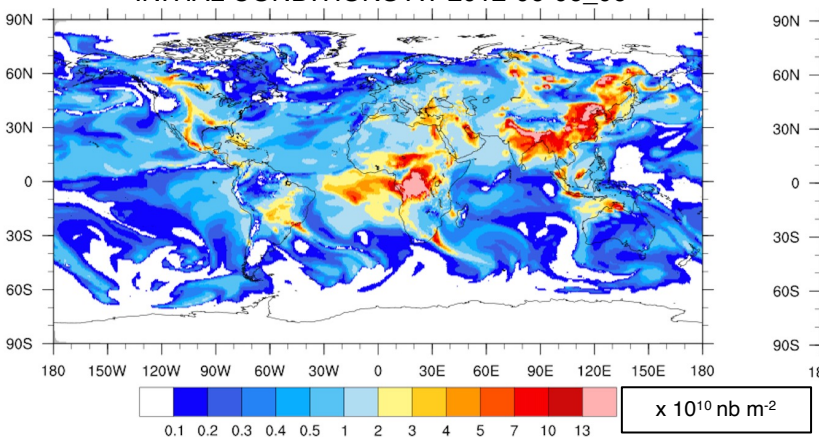
Ice-friendly (non-hygroscopic) aerosols

The number concentration of nifa is similar to that of the MAM4 coarse mode.

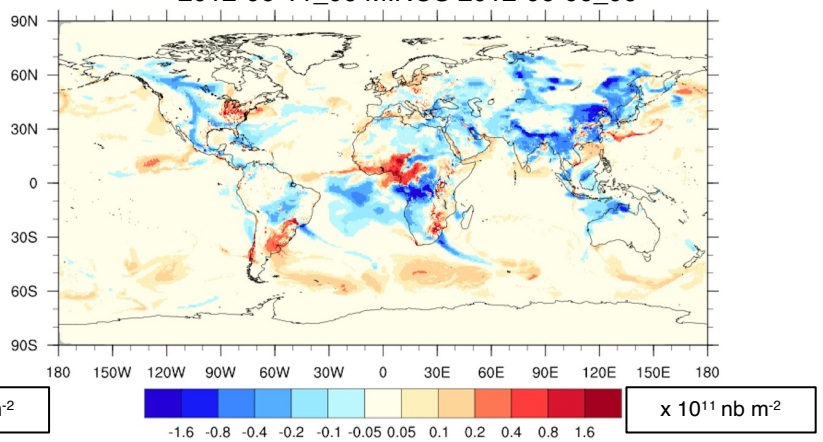
RESULTS AT END OF 5-DAY SPINUP (at 2012-06-06_06 UTC)

WATER-FRIENDLY AEROSOLS IN LAYER ADJACENT TO SURFACE

a) INITIAL CONDITIONS AT 2012-06-06_06

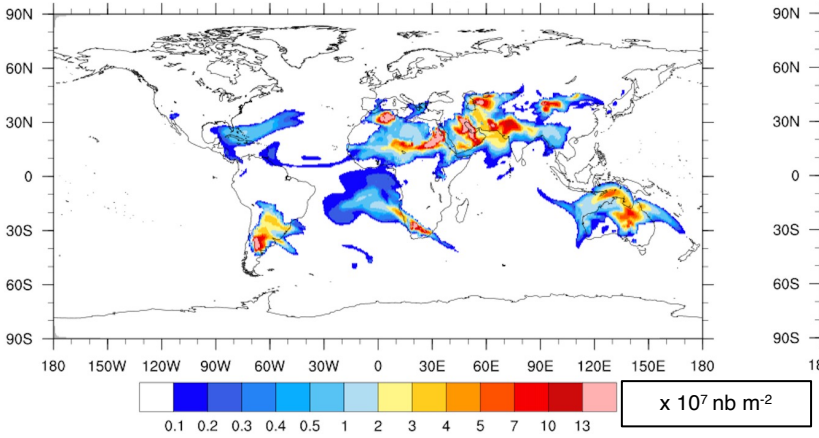


b) 2012-06-11_06 MINUS 2012-06-06_06

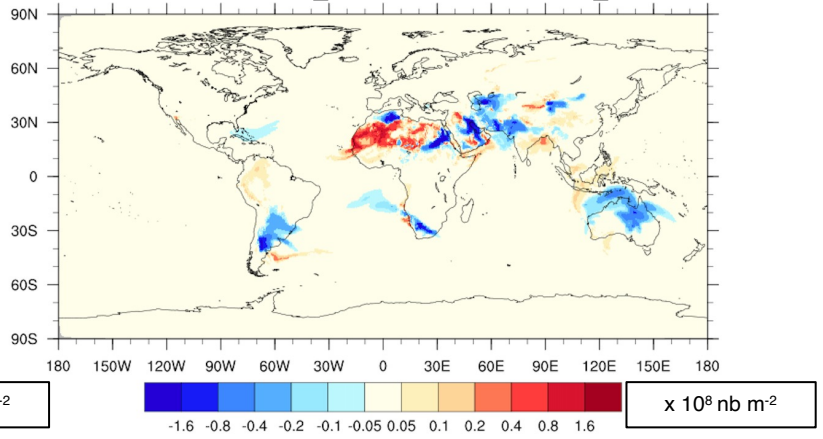


ICE-FRIENDLY AEROSOLS IN LAYER ADJACENT TO SURFACE

c) INITIAL CONDITIONS AT 2012-06-06_06

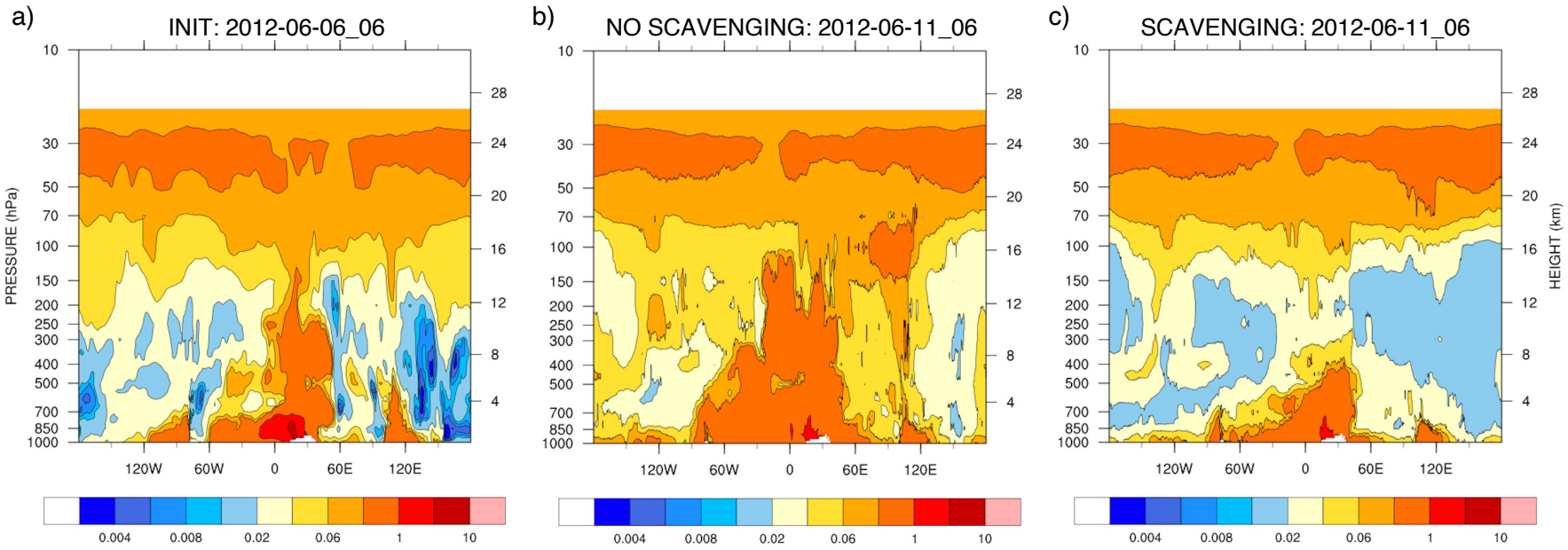


d) 2012-06-11_06 MINUS 2012-06-06_06



RESULTS AT END OF 5-DAY SPINUP (at 2012-06-06_06 UTC)

[EQ-10°S] AVERAGED WATER-FRIENDLY AEROSOLS (x 10^9 nb kg^{-1})



Conclusions and Future work

1. We built and tested a novel initialization of aerosols in MPAS:
   - We mapped CAM-Chem/MAM4 aerosols to the *Thompson* aerosols.
   - We implemented realistic surface emissions of anthropogenic and natural (primary) aerosols (dust, sea salt).
   - Initial spinup runs are as we expect and encouraging.

2. Future work includes
   - Redo some of the earlier experiments that we did without surface emissions.
   - Expand our implementation to variable-resolution experiments.