SIMULATE CO_2 USING WRF/CHEM-VPRM

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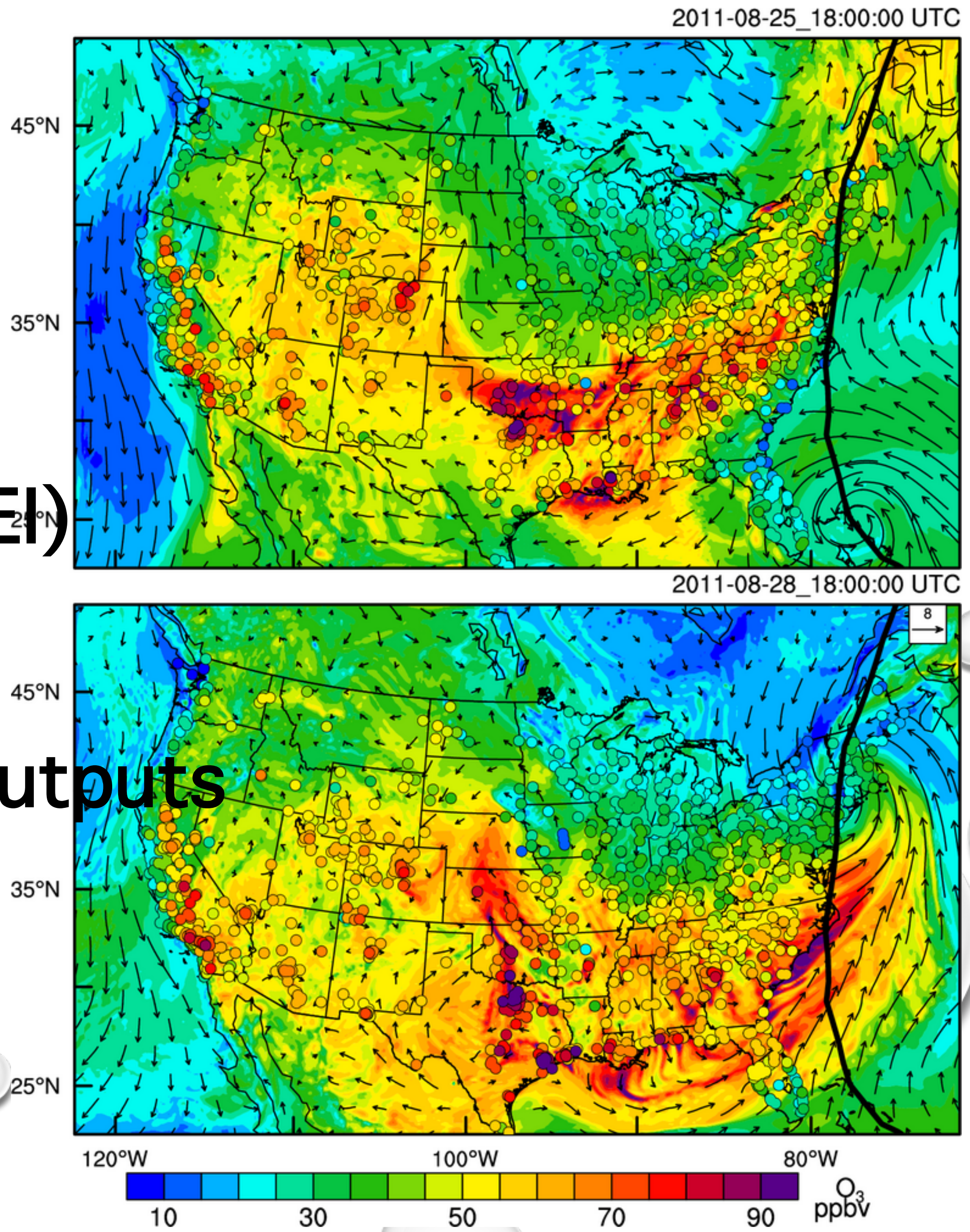
June 13, 2017
@HuNan

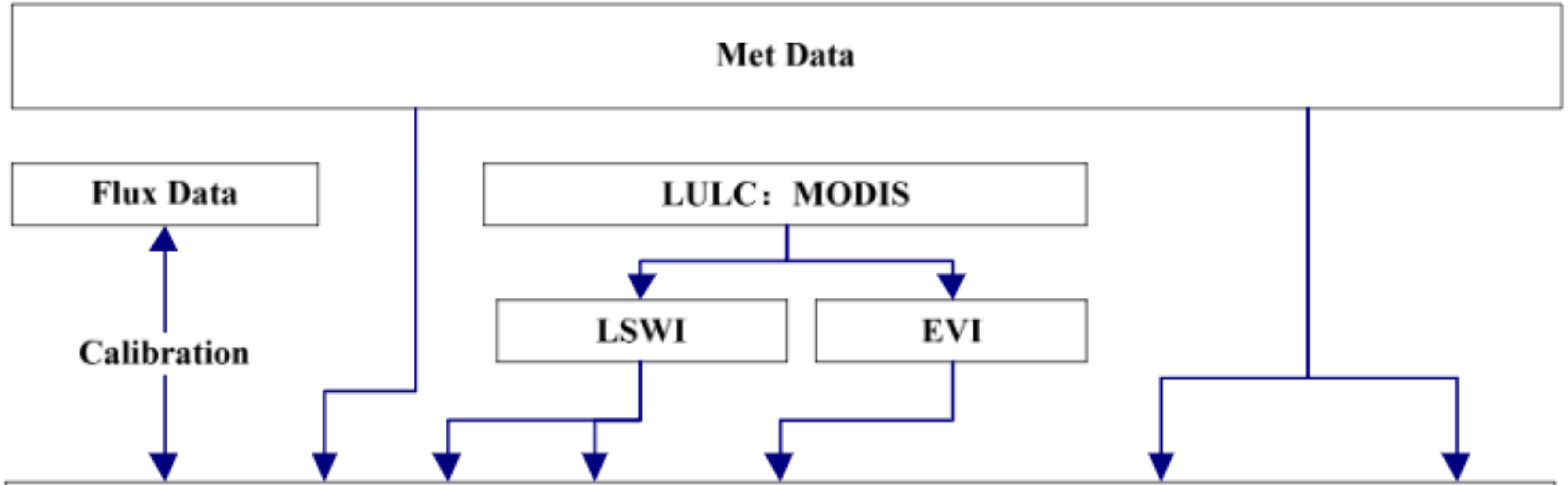
WRF/CHEM FOR AIR QUALITY SIMULATIONS

- **Anthropogenic emissions:** National Emissions Inventory (NEI)
- **Biogenic emissions:** MEGAN biogenic emissions
- **Chemical IC and BC:** MOZART4 outputs
- **Gas reactions:** RACM



WRF/CHEM-VPRM FOR CO2 SIMULATION

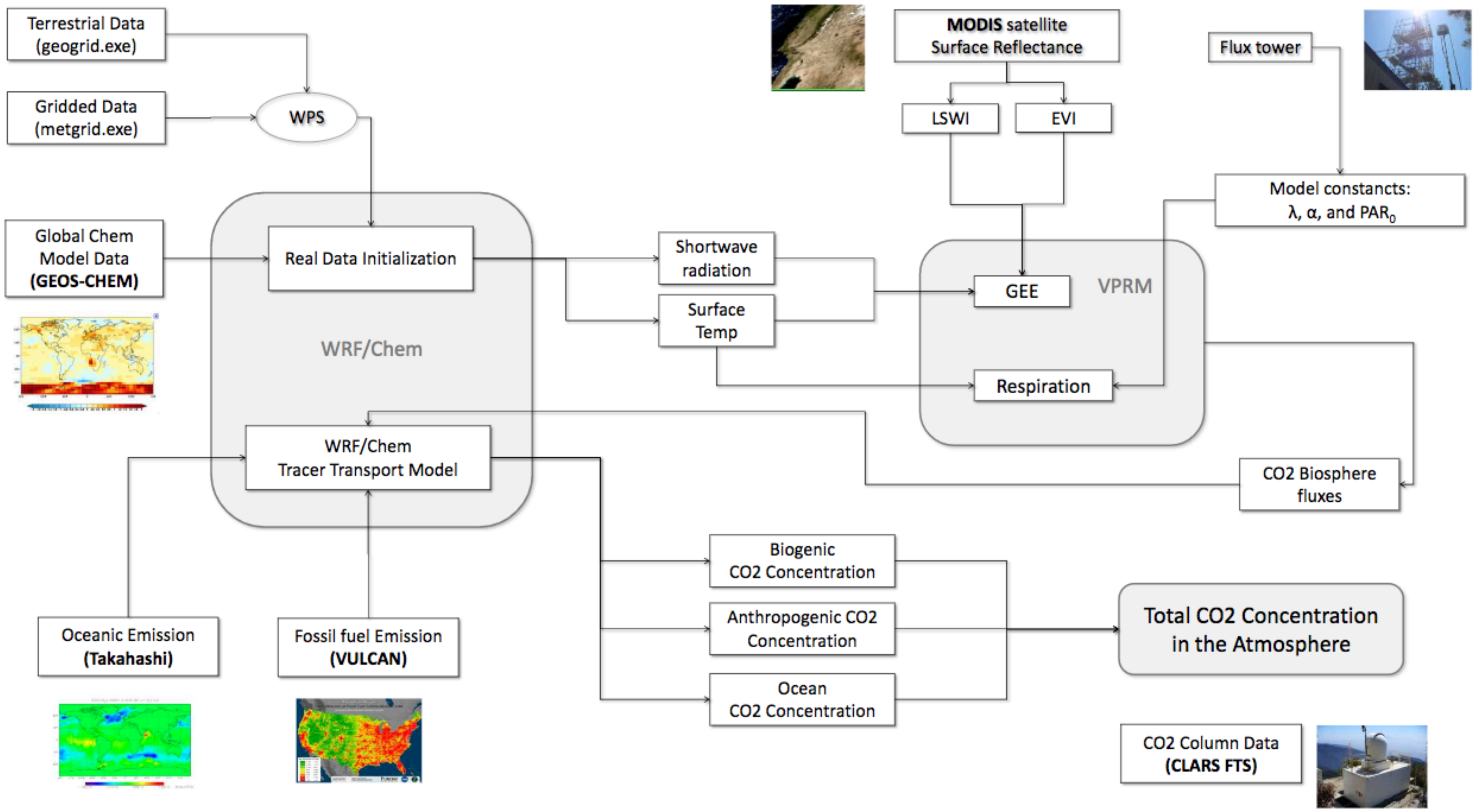
- Vegetation Photosynthesis and Respiration Model (VPRM) (Xiao et al., 2004)

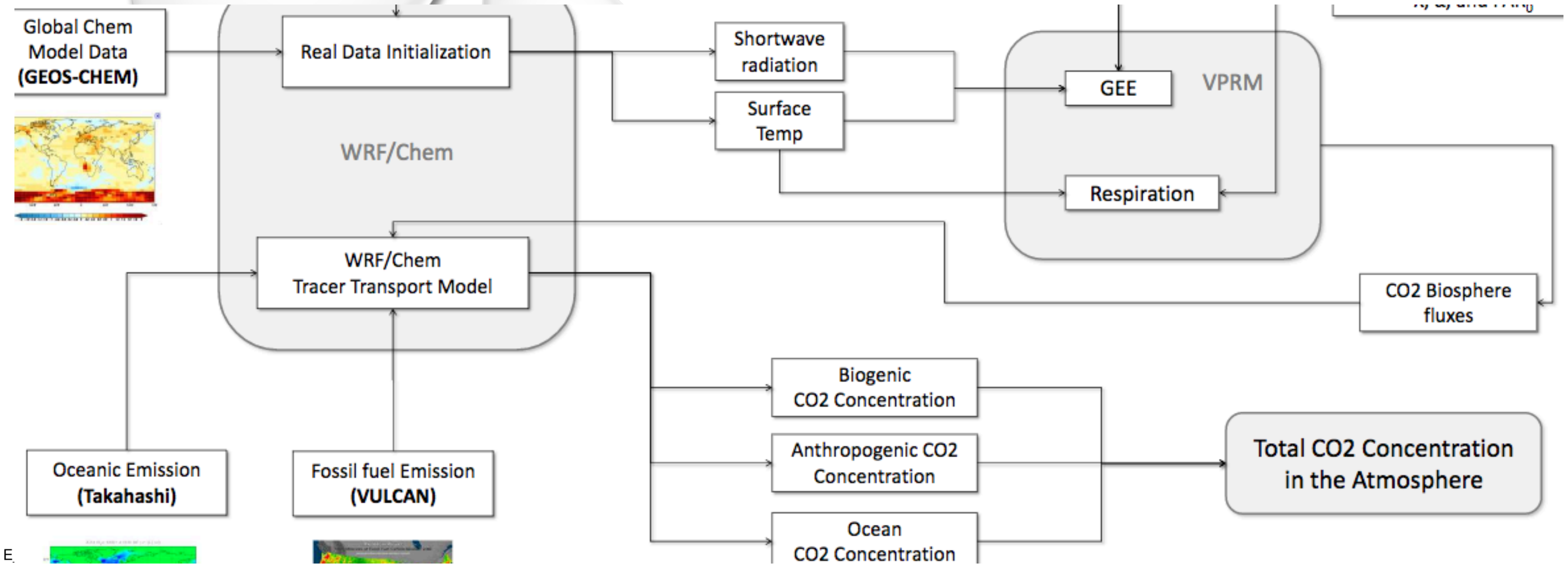


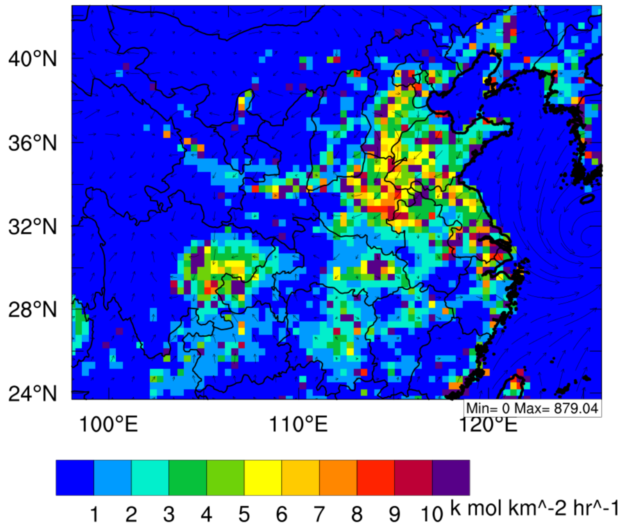
$$GEE = (\lambda \times T_{scale} \times W_{scale} \times P_{scale}) \times FAPAR_{PAV} \times 1/(1 + PAR/PAR_0) \times PAR$$

$$Respiration = \alpha \times T_a + \beta$$

Xiao, X. M., D. Hollinger, J. Aber, M. Goltz, E. A. Davidson, Q. Y. Zhang, and B. Moore, 2004: Satellite-based modeling of gross primary production in an evergreen needleleaf forest. *Remote Sens Environ*, **89,** 519-534, 10.1016/j.rse.2003.11.008.


Terrestrial Data (geogrid.exe)
Gridded Data (metgrid.exe)
WPS
Global Chem Model Data (GEOS-CHEM)
Real Data Initialization
WRF/Chem
WRF/Chem Tracer Transport Model
Oceanic Emission (Takahashi)
Fossil fuel Emission (VULCAN)
MODIS satellite Surface Reflectance
LSWI
EVI
Flux tower
Model constancts: λ, α, and PAR_0
Shortwave radiation
Surface Temp
GEE
VPRM
Respiration
CO2 Biosphere fluxes
Biogenic CO2 Concentration
Anthropogenic CO2 Concentration
Ocean CO2 Concentration
Total CO2 Concentration in the Atmosphere
CO2 Column Data (CLARS FTS)





EDGAR

Just like we provide NEI for air quality simulation
Note: only 1 layer, need PREP_CHEM_SRC program

bio_emiss_opt	= 0	no biogenic emissions
	= 1	calculates biogenic emissions online using the Gunther scheme
	= 2	includes biogenic emissions reference fields in wrfinput data file and modify values online based upon the weather
	= 3	includes MEGAN biogenic emissions online based upon the weather, land use data. Need to include ne_area setting, the total number of chemical species, in the chemical namelist.
	= 16	Include CO_2 biomass emissions from the VPRM model. (Requires user to provide external files through auxiliary input port 15.)

Use a matlab code to put EVI, LSWI into auxinput16.

Software requirements

- GNU Linux/Unix OS
  - tested on x86_64 Suse Linux
- GNU Bash
  - tested with version 2.05b.0(1)
- HDF5 tools
  - tested with version 1.6.4
  - obtained from: http://www.hdfgroup.org/HDF5/
- H4toH5 conversion tool
  - tested with version 1.2
  - obtained from: http://www.hdfgroup.org/h4toh5/
- MODIS Land Data Operational Product Evaluation (LDOPE) tool
  - tested with version: 1.0
  - obtained from: http://gcmd.nasa.gov/records/LDOPE.html
- MODIS Reprojection Tool (MRT)
  - tested with version: 3.3
  - optained from https://lpdaac.usgs.gov/lpdaac/tools/modis_reprojection_tool
- NETCDF library and tools
  - tested with version: 3.6.0-p1
  - optained from: http://www.unidata.ucar.edu/software/netcdf/
- R
  - tested with version: 2.5.1
  - optained from: http://cran.r-project.org/
- Rmap package for R
  - tested with version: 1.1.0
  - obtained from: http://www.maths.lancs.ac.uk/Software/Rmap/
- HDF package for R (hdf5)
  - tested with version 1.6.2
  - obtained from: http://cran.r-project.org/
- NETCDF package for R (RNetCDF)
  - tested with version 1.2-1
  - obtained from: http://cran.r-project.org/

Biogeosciences, 6, 807–817, 2009
www.biogeosciences.net/6/807/2009/

Biogeosciences

Comparing high resolution WRF-VPRM simulations and two global CO_2 transport models with coastal tower measurements of CO_2

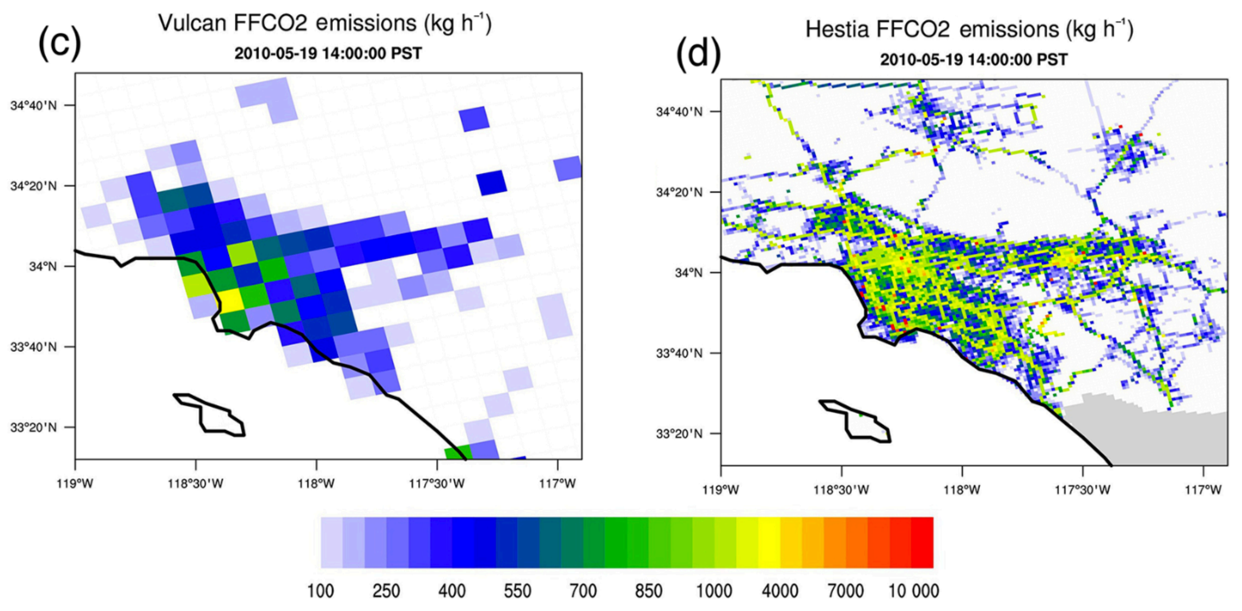
R. Ahmadov[1], C. Gerbig[1], R. Kretschmer[1], S. Körner[1], C. Rödenbeck[1], P. Bousquet[2], and M. Ramonet[2]

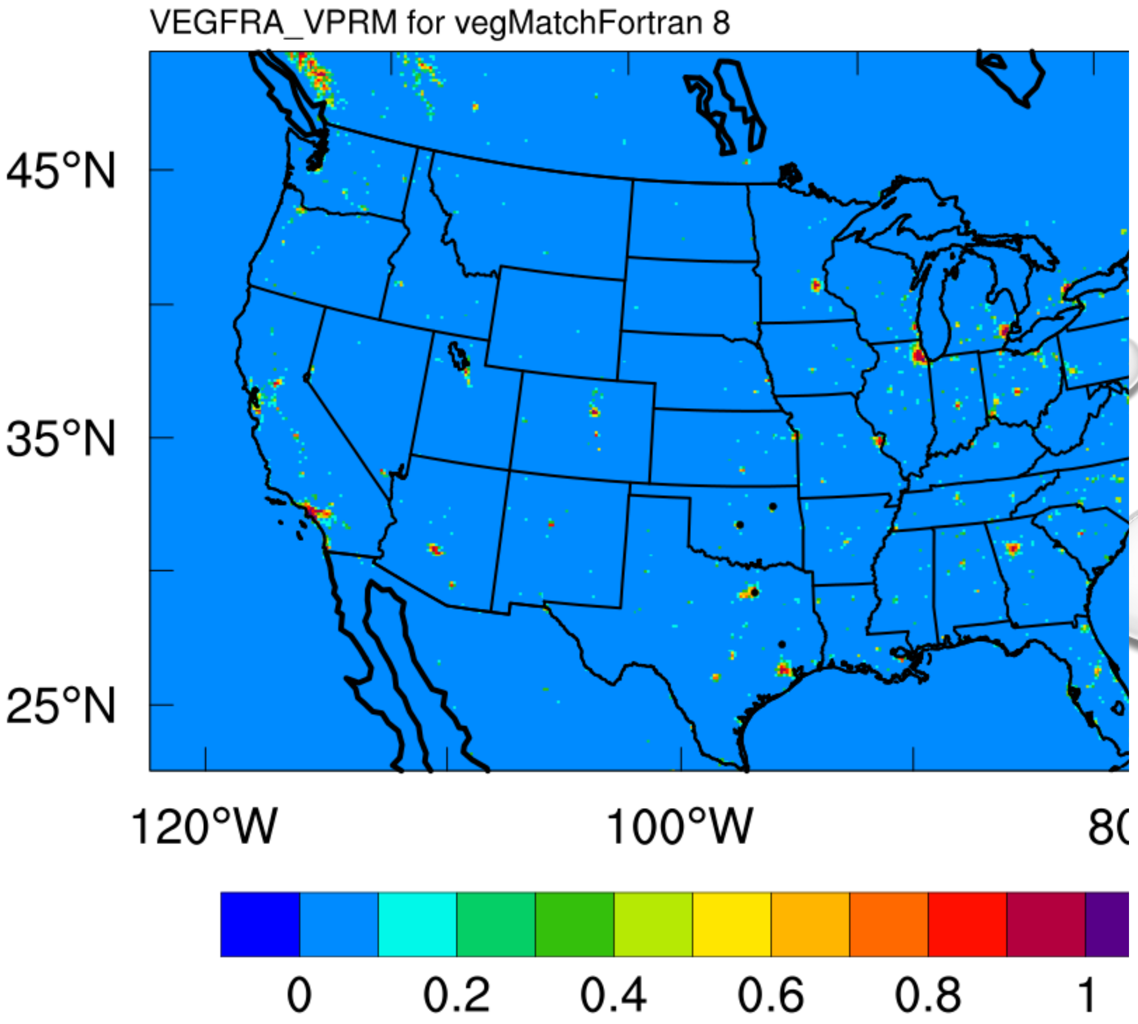
[1]Max-Planck-Institute for Biogeochemistry, Hans-Knöll-Str. 10, 07745, Jena, Germany
[2]Laboratoire des Sciences du Climat et de l-Environnement, UMR CEA-CNRS 1572, 91191 Gif-sur-Yvette, France

Only published WRF-VPRM paper over US: no much CO2_BIO and lots of issues!

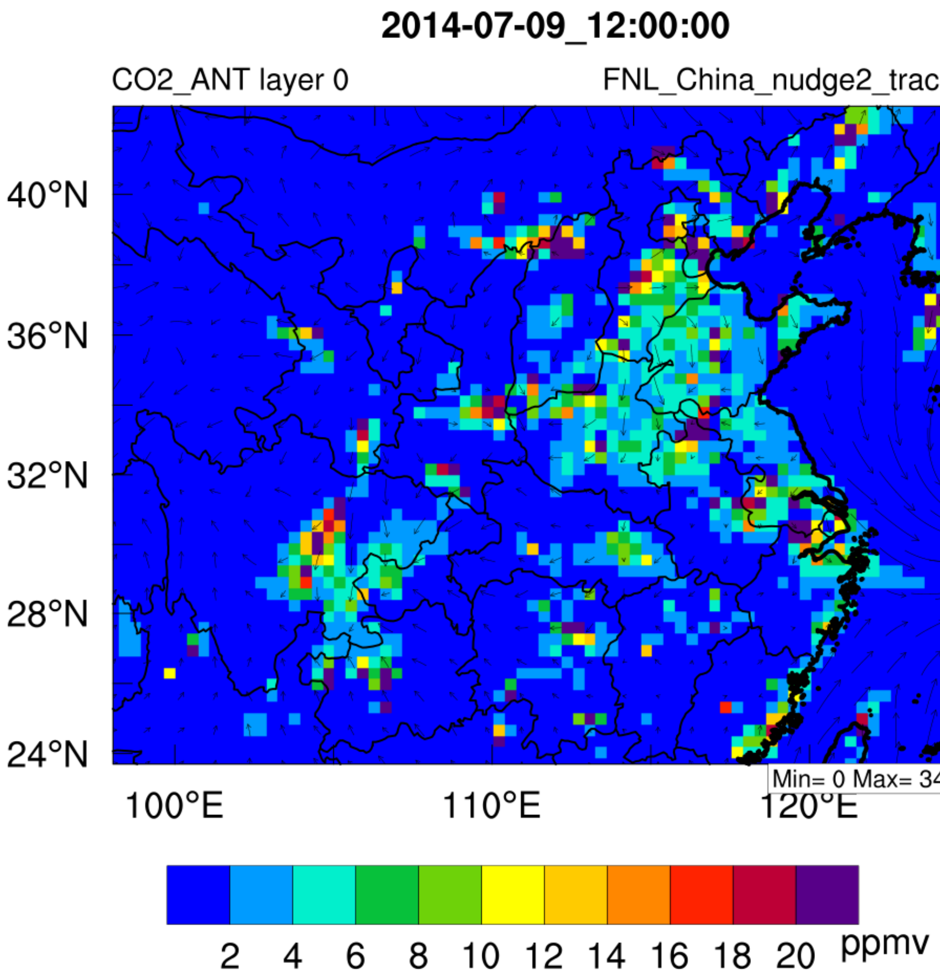
Los Angeles megacity: a high-resolution land–atm
system for urban CO_2 emissions

Sha Feng[1,2,a], Thomas Lauvaux[3,2], Sally Newman[4], Preeti Rao[2], Ravan Ahmadov[5,6], Ai
Riley M. Duren[2], Marc L. Fischer[7], Christoph Gerbig[8], Kevin R. Gurney[9], Jianhua Hu
Zhijin Li[2], Charles E. Miller[2], Darragh O'Keeffe[9], Risa Patarasuk[9], Stanley P. Sander[2
Kam W. Wong[4,2], and Yuk L. Yung[4]

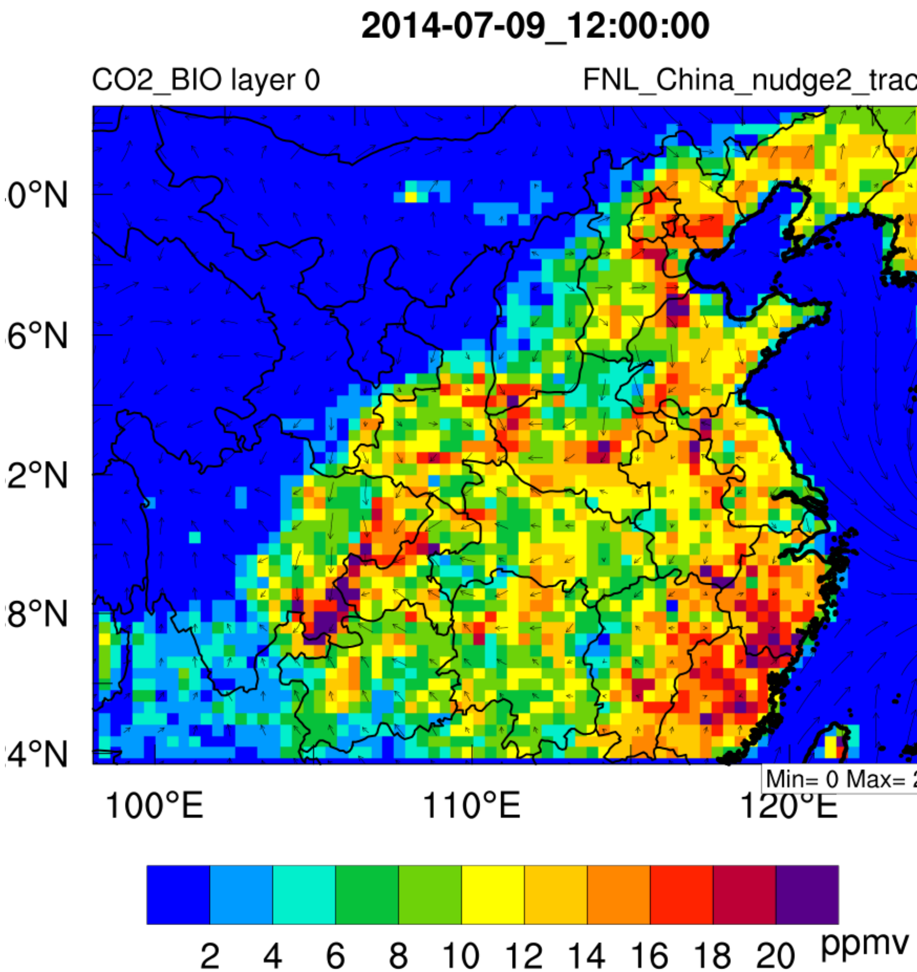




First test results over China Domain:
http://www.caps.ou.edu/micronet/CO2_and_otherGHG.html

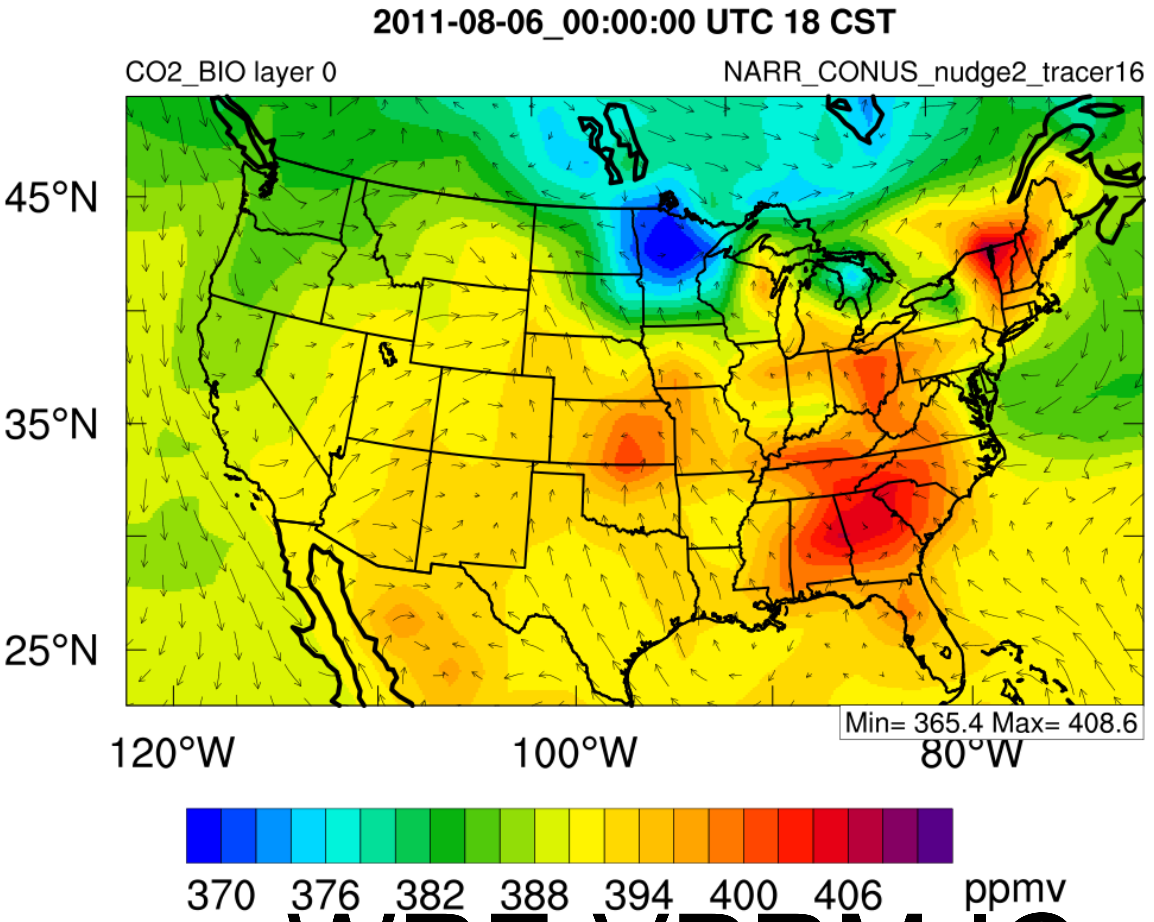


Anthropogenic CO_2

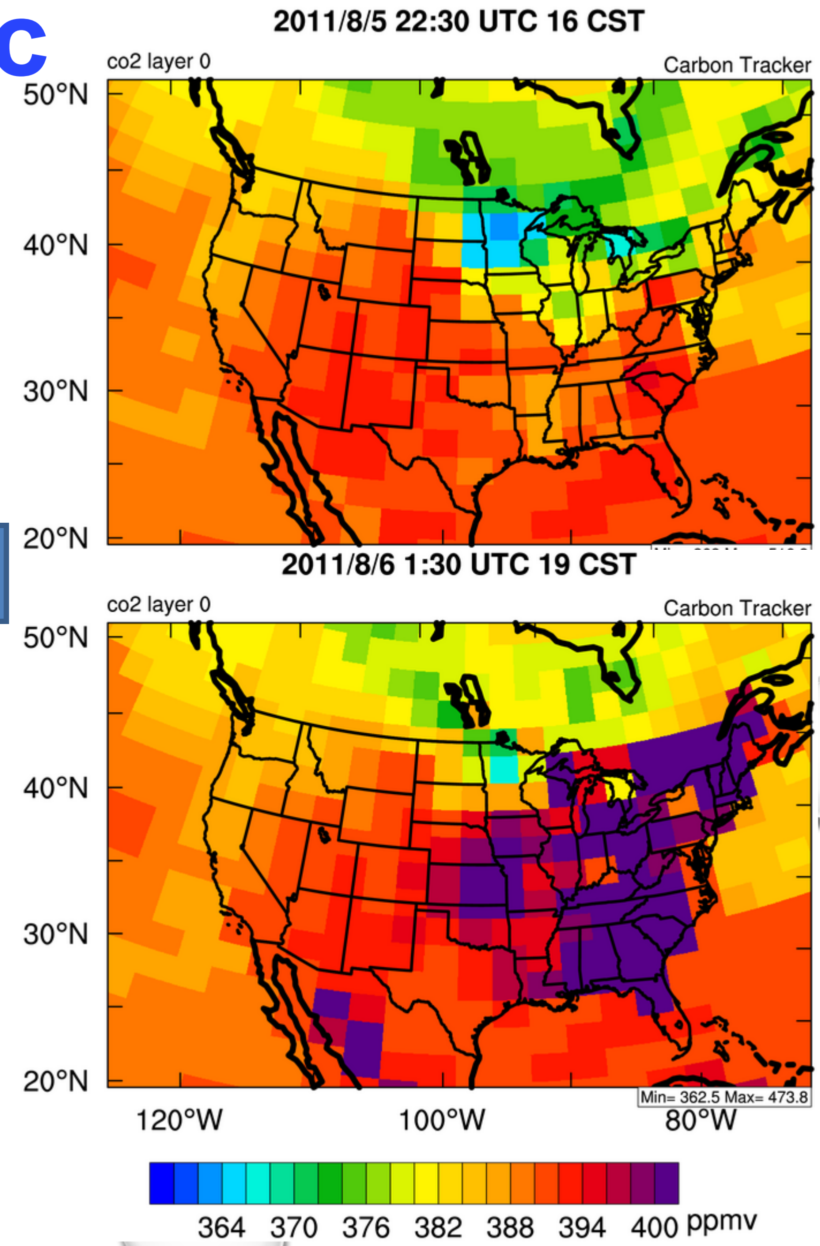


Biogenic CO_2

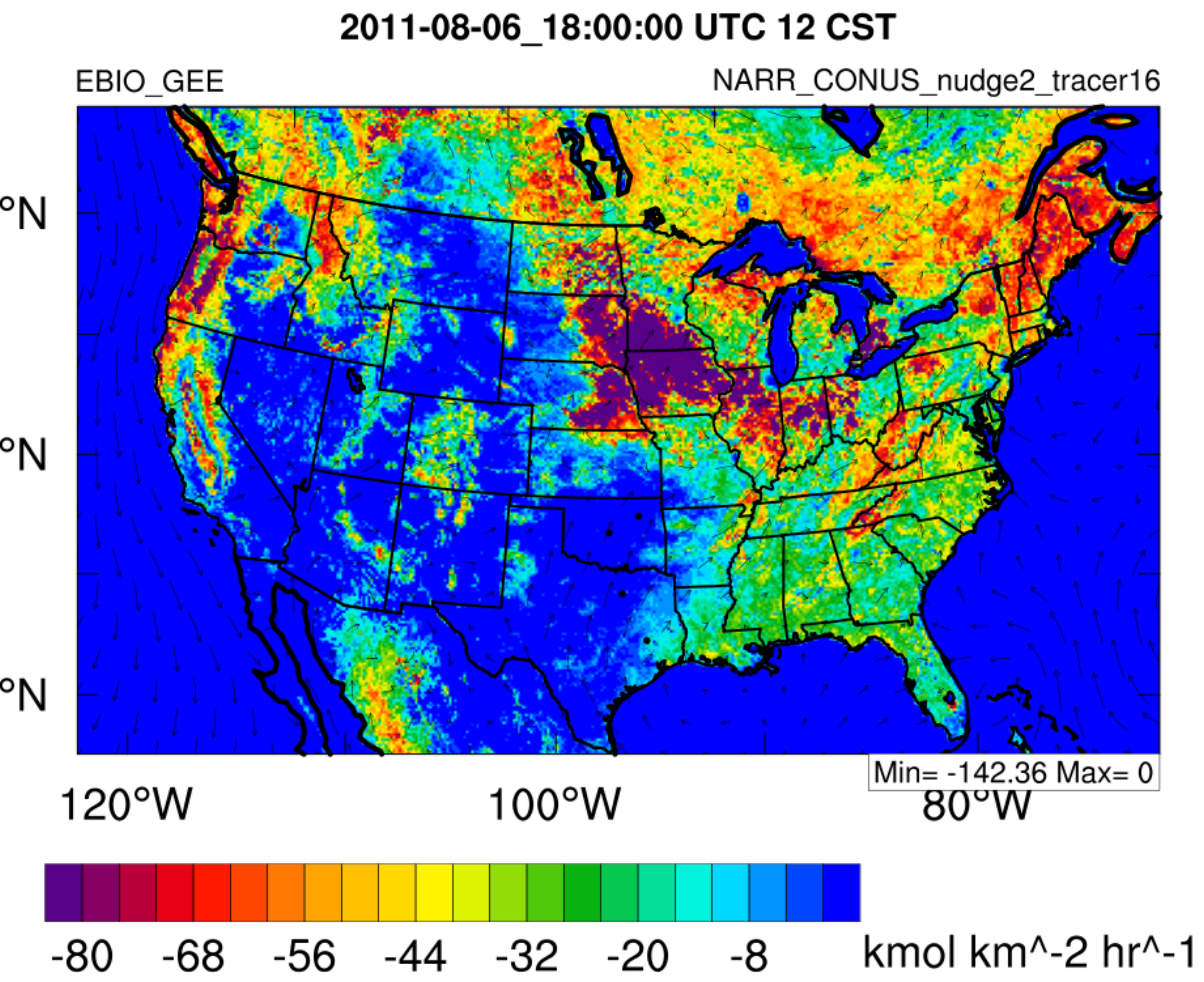
Code developed to extract IC/BC from carbon tracker based on mozbc



WRF-VPRM IC

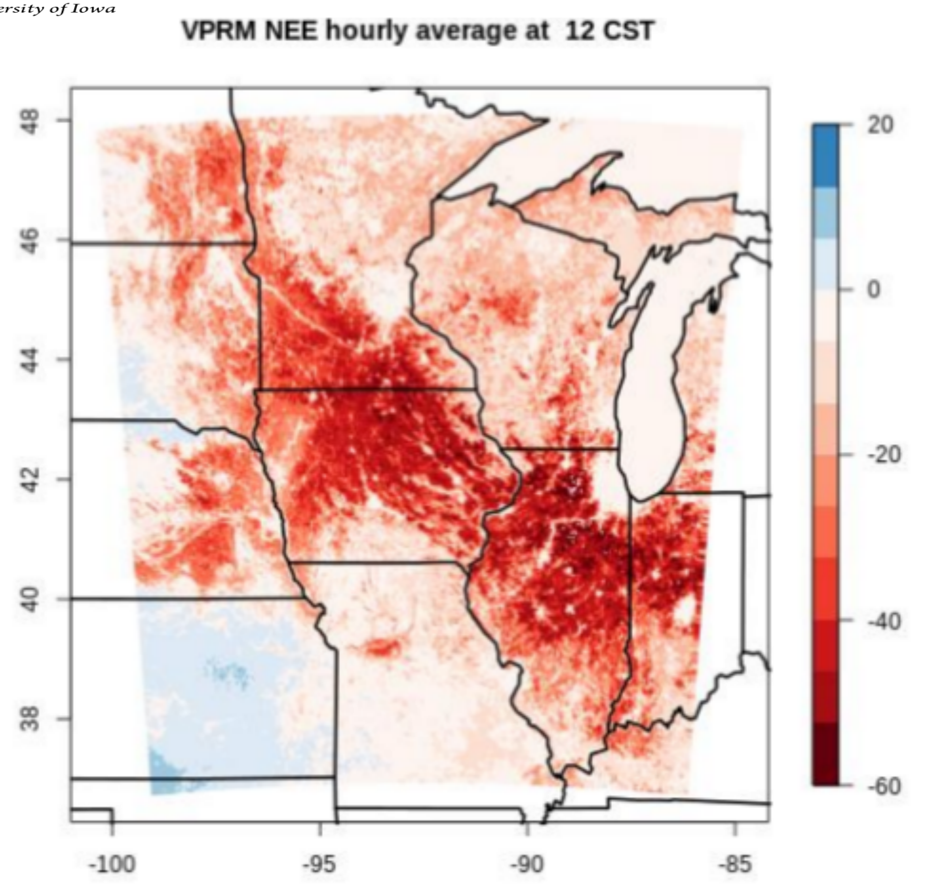


Compare with Jamroensan (2013) thesis



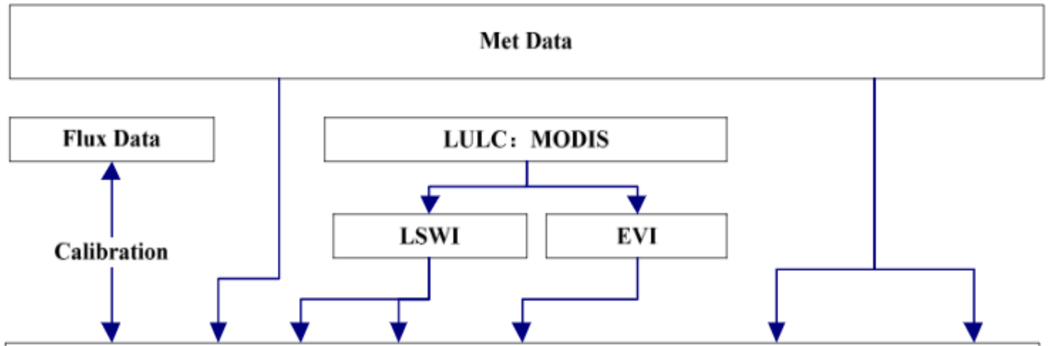
Improving bottom-up and top-down estimates of carbon fluxes in the Midwestern USA

Aditsuda Jamroensan
University of Iowa



ıre 6.18 NEE flux hourly average (from August 1st, 2012 – August 7th, 2012) at 12 pm CST when using Ameriflux optimized VPRM parameters and multi-crop.

Current issues for application over US

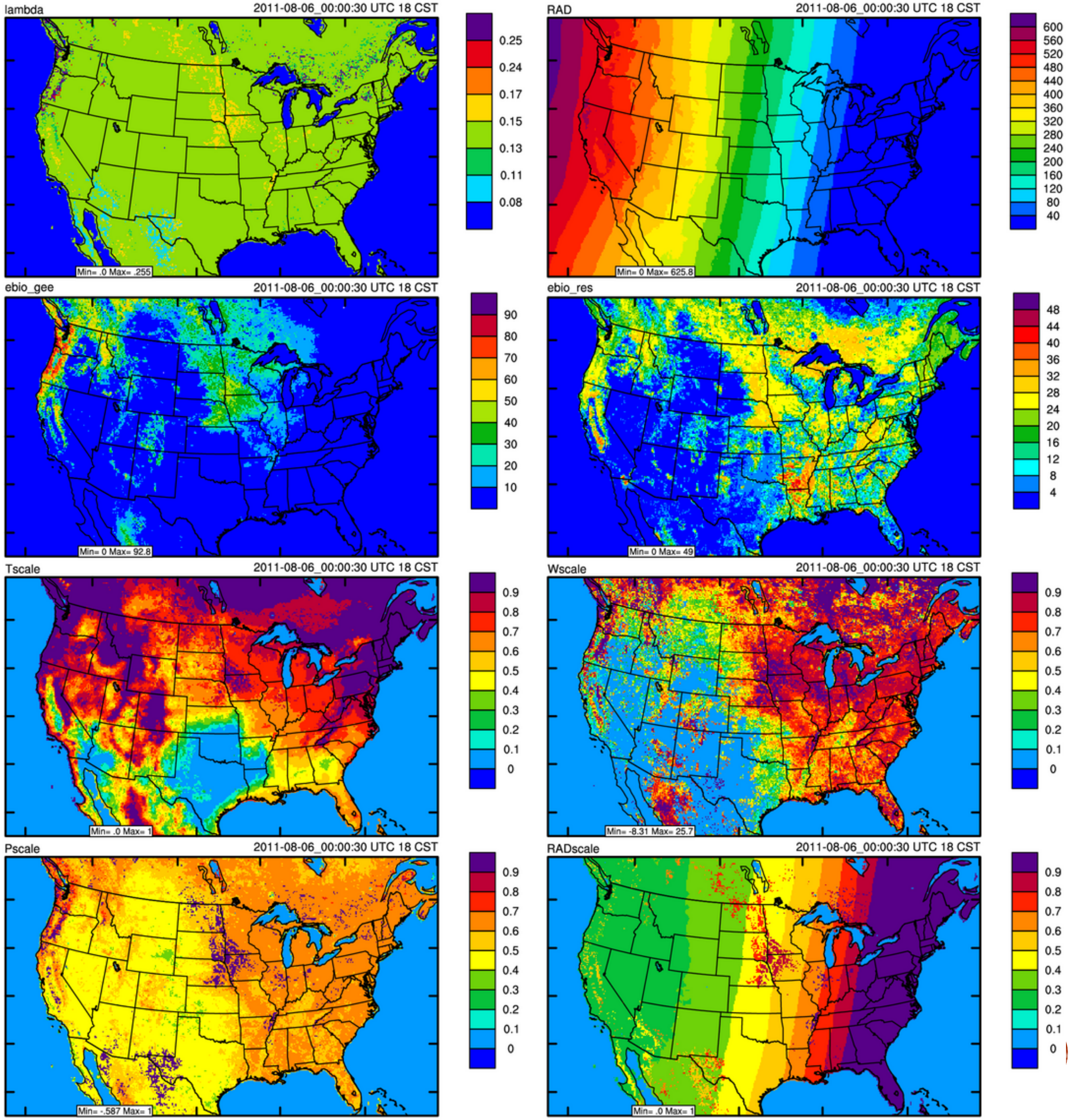


$$GEE = (\lambda \times T_{scale} \times W_{scale} \times P_{scale}) \times FAPAR_{PAV} \times 1/(1 + PAR/PAR_0) \times PAR$$

$$Respiration = \alpha \times T_a + \beta$$

4 parameters, 4 scalars/scales

Need to add more limiters make sure the scales are between 0 and 1

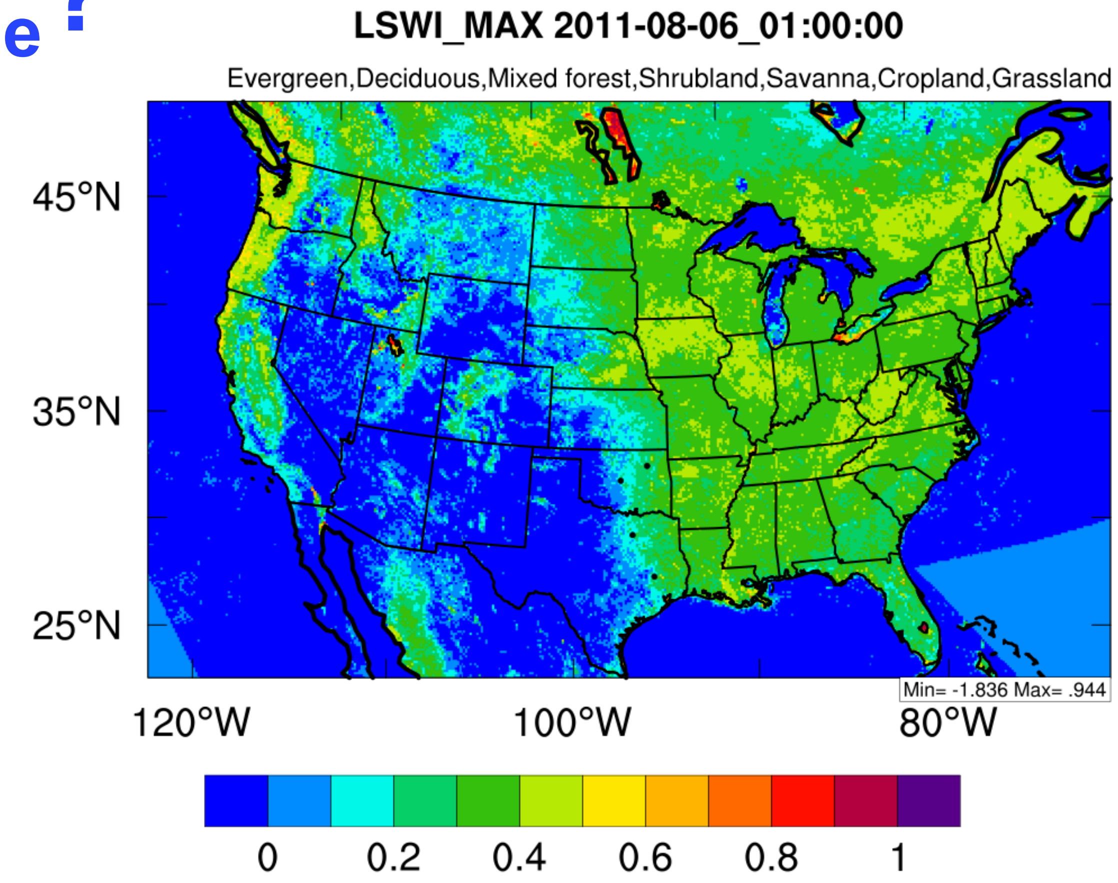


Should we improve W_{scale}?

no much CO2 diurnal variation over southern GP and western US, reasonable?

α=0.0269 Grassland, over southern GP

GEE also 0 since LSWI_MAX < 0



for drought conditions

For drought periods, we suggested a modified W_{scalar} estimation approach as follows:

$$W_{scalar} = \text{long-term } LSWI_{max} + LSWI.$$

Wagle, Xiao et al. (2014)

$$W_{scale}(\text{grassland/savanna}) = \frac{(LSWI - LSWI_{min})}{(LSWI_{max} - LSWI_{min})}$$

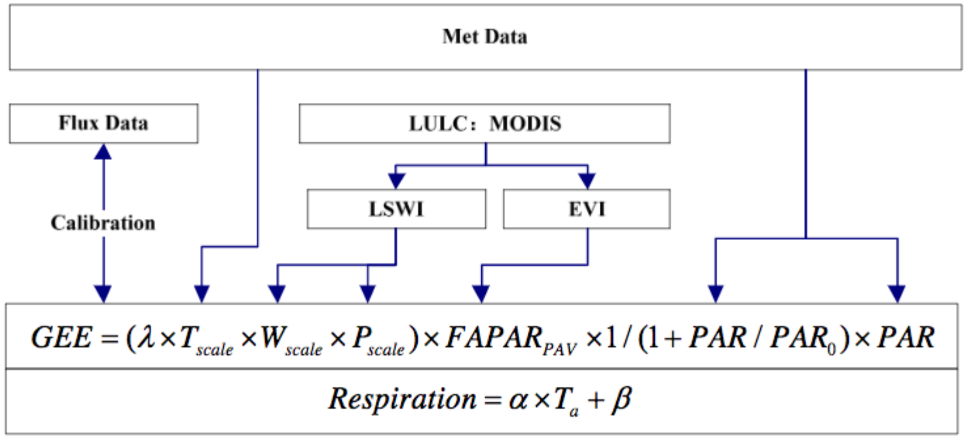
For veg 4 & 7 (Shrubland and grassland)

$$W_{scale}(\text{other vegetation types}) = \frac{(1 + LSWI)}{(1 + LSWI_{max})}$$

Matross et al. (2006, Tellus)

```
Tair= T2(i,j)-273.15
veg_frac_loop: DO m=1,7

      if (vprm_in(i,m,j,p_vegfra_vprm)<1.e-8) CYCLE  ! Then fluxes are zero

      a1= Tair-Tmin(m)
      a2= Tair-Tmax(m)
      a3= Tair-Topt(m)

      ! Here a1 or a2 can't be negative
      if (a1<0. .OR. a2>0.) then
          Tscale= 0.
      else
          Tscale=a1*a2/(a1*a2 - a3**2)
      end if

      if (Tscale<0.) then
          Tscale=0.
      end if

     ! modification due to different dependency on ground water
      if (m==4 .OR. m==7) then  ! grassland and shrubland are xeric systems
          if (vprm_in(i,m,j,p_lswi_max)<1e-7) then  ! in order to avoid NaN for Wscale
              Wscale= 0.
          else
              Wscale= (vprm_in(i,m,j,p_lswi)-vprm_in(i,m,j,p_lswi_min))/(vprm_in(i,m,j,p_lswi_max)-vprm_in(i,m,j,p_lswi_min))
          end if
      else
          Wscale= (1.+vprm_in(i,m,j,p_lswi))/(1.+vprm_in(i,m,j,p_lswi_max))
      end if

      ! effect of leaf phenology
      if (m==1) then  ! evegreen
          Pscale= 1.
      else if (m==5 .OR. m==7) then  ! savanna or grassland
          Pscale= (1.+vprm_in(i,m,j,p_lswi))/2.
      else                              ! Other vegetation types
          evithresh= vprm_in(i,m,j,p_evi_min) + 0.55*(vprm_in(i,m,j,p_evi_max)-vprm_in(i,m,j,p_evi_min))
          if (vprm_in(i,m,j,p_evi)>=evithresh) then  ! Full canopy period
             Pscale= 1.
          else
             Pscale=(1.+vprm_in(i,m,j,p_lswi))/2.  ! bad-burst to full canopy period
          end if
      end if

      RADscale= 1./(1. + RAD(i,j)/rad0(m))
      GEE_frac= lambda(m)*Tscale*Pscale*Wscale*RADscale* vprm_in(i,m,j,p_evi)* RAD(i,j)*vprm_in(i,m,j,p_vegfra_vprm) + GEE_frac

      RESP_frac= (alpha(m)*Tair + RESP0(m))*vprm_in(i,m,j,p_vegfra_vprm) + RESP_frac


ENDDO veg_frac_loop
```

```fortran
DATA vprm_table_us &
     / 261.0, 324.0, 206.0, 363.0, 682.0, 757.0, 157.0, 0.0, &
      -0.2492, -0.1729, -0.2555, -0.08736, -0.1141, -0.15330, -0.13335, 0.00000, &
       0.3301, 0.3258, 0.3422, 0.0239, 0.0049, 0.2680, 0.0269, 0.0000, &
       0., 0., 0., 0., 0., 0., 0., 0. /

DATA vprm_table_europe &
     / 270.2, 271.4, 236.6, 363.0, 682.0, 690.3, 229.1, 0.0, &
      -0.3084, -0.1955, -0.2856, -0.0874, -0.1141, -0.1350, -0.1748, 0.0000, &
       0.1797, 0.1495, 0.2258, 0.0239, 0.0049, 0.1699, 0.0881, 0.0000, &
       0.8800, 0.8233, 0.4321, 0.0000, 0.0000, -0.0144, 0.5843, 0.0000 /

! Tropics are still preliminary, too strong SWDOWN might cause too high uptake
DATA vprm_table_tropics &
     / 501.0, 324.0, 206.0, 303.0, 682.0, 646.0, 157.0, 0.0, &
      -0.2101, -0.1729, -0.2555, -0.0874, -0.1141, -0.1209, -0.1334, 0.0000, &
       0.1601, 0.3258, 0.3422, 0.0239, 0.0049, 0.0043, 0.0269, 0.0000, &
       0., 0., 0., 0., 0., 0., 0., 0. /

TYPE (grid_config_rec_type) , INTENT (IN) :: config_flags

sel_pars: SELECT CASE(config_flags%vprm_opt)
CASE ('VPRM_table_US')
  vprm_par=vprm_table_us
CASE ('VPRM_table_EUROPE')
  vprm_par=vprm_table_europe
CASE ('VPRM_table_TROPICS')
  vprm_par=vprm_table_tropics
CASE DEFAULT
  CALL wrf_message("check vprm_opt in namelist.input")
  CALL wrf_error_fatal ( "NO PARAMETER TABLE IS INCLUDED FOR THIS VPRM TABLE OPTION!")
END SELECT sel_pars

rad_vprm=     vprm_par(1:8,1)
lambda_vprm=  vprm_par(1:8,2)
alpha_vprm=   vprm_par(1:8,3)
resp_vprm=    vprm_par(1:8,4)
```



Uncertainties: 4 parameters

β=0

```
Warning: the VPRM parameters may need to be optimized depending on the season, year and region!
The parameters provided here should be used for testing purposes only!
```

Confusing units, issue with λ and PAR_0

[17] The complete expression for GEE in the VPRM is thus given by

$$GEE = \lambda \times T_{scale} \times P_{scale} \times W_{scale} \times EVI \times \frac{1}{(1 + PAR/PAR_0)} \times PAR \quad (9)$$

Here λ replaces ε_0, in order to aggregate into one parameter empirical adjustments to P_{scale}, T_{scale}, and W_{scale}; λ and PAR_0 are the only adjustable parameters for description of the light-dependent part of NEE, with values derived below from tower flux data.

[18] *PAR* is measured at all flux tower sites, but not across the continent. At large scales the VPRM will be driven using shortwave (SW) radiation, available for almost all of North America from Geostationary Operational Environmental Satellite (GOES) data [e.g., *Diak et al.*, 2004] and from assimilated meteorological products. SW is very closely correlated with PAR; SW $\approx$ 0.505 $\times$ PAR (units: SW, Watts/m^2; PAR, μmole m^{-2} s^{-1}).

Mahadevan et al. (2008, GBC)

PAR (μmol m^{-2} s^{-1}) is acutally SWDOWN (W m^{-2}) in the model

λ: μmole CO_2 m^{-2} s^{-1}/μmole PAR m^{-2} s^{-1}

Does it mean

λ: μmole CO_2 m^{-2} s^{-1}/Watts m^{-2}

Can we believe Table 2 and compare with other studies?

Table 2. Parameters PAR_0, λ, α, β, and Their Variances and Light Use Efficiency at Calibration Sites[a]

Site	T_{min}	T_{opt}	T_{max}	T_{low}	PAR_0	λ	α	β	σ-PAR_0
HARVARD	0	20	40	5	570	0.127	0.271	0.25	14
HOWLAND	0	20	40	2	629	0.123	0.244	−.24	17
NOBS	0	20	40	1	262	0.234	0.244	0.14	5
NIWOT	0	20	40	1	446	0.128	0.250	0.17	13
METOLIUS	0	20	40	2	1206	0.097	0.295	−.43	39
SOY_MEADS2	5	22	40	2	2051	0.064	0.209	0.20	137
CORN_MEAD	5	22	40	2	11250	0.075	0.173	0.82	1746
TONZI	2	20	40	-	3241	0.057	0.012	0.58	293
VAIRA	2	18	40	-	542	0.213	0.028	0.72	23
DONALDSON	0	20	40	1	790	0.114	0.153	1.56	18
LUCKY-HILLS	2	20	40	-	321	0.122	0.028	0.48	14
PEATLAND	0	20	40	3	558	0.051	0.081	0.24	23

[a]Units are as follows: PAR_0: μmole m^{-2} s^{-1}; λ: μmole CO_2 m^{-2} s^{-1}/μmole PAR m^{-2} s^{-1}; α: μmole CO_2 m^{-2} s^{-1}/°C
use efficiency: λ.

Wagle et al. (2014): The largest observed ε_0 value was 0.062 ± 0.0066 (standard error) mol CO_2 mol^{-1} PPFD at the Fermi site during the week June 24–30, 2007.
As a result of drought, smaller ε_0 values were observed at the El Reno sites. The highest observed ε_0 values were 0.035 ± 0.0018 mol CO_2 mol^{-1} PPFD (July 8–15, 2005) at the El Reno control site

Hilton et al.: Spatial structure in land surface model residuals

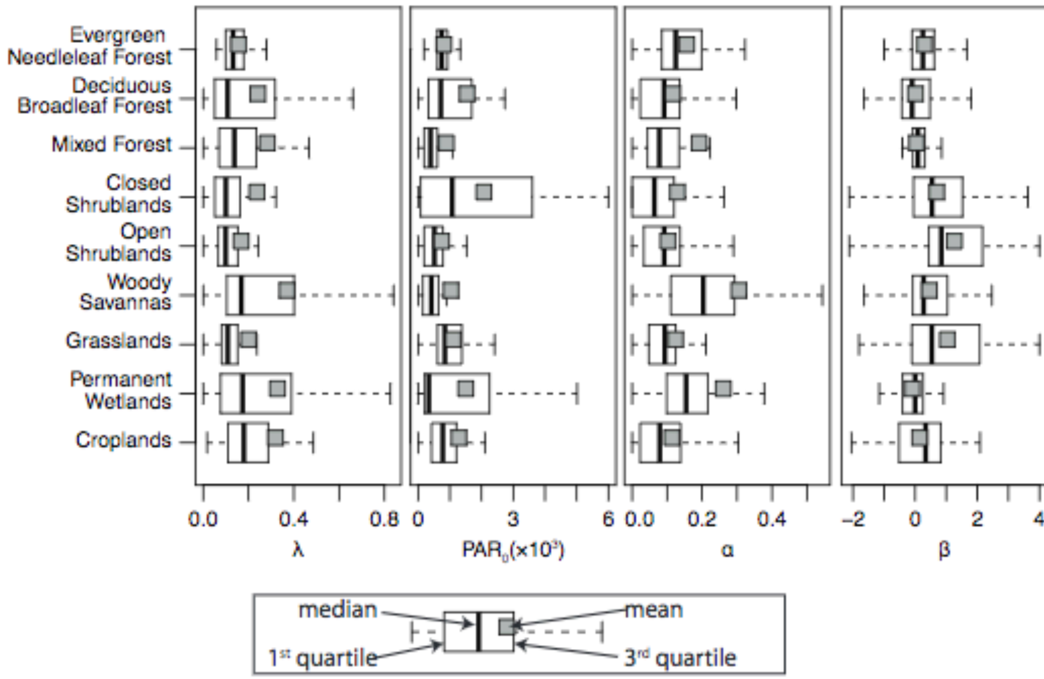
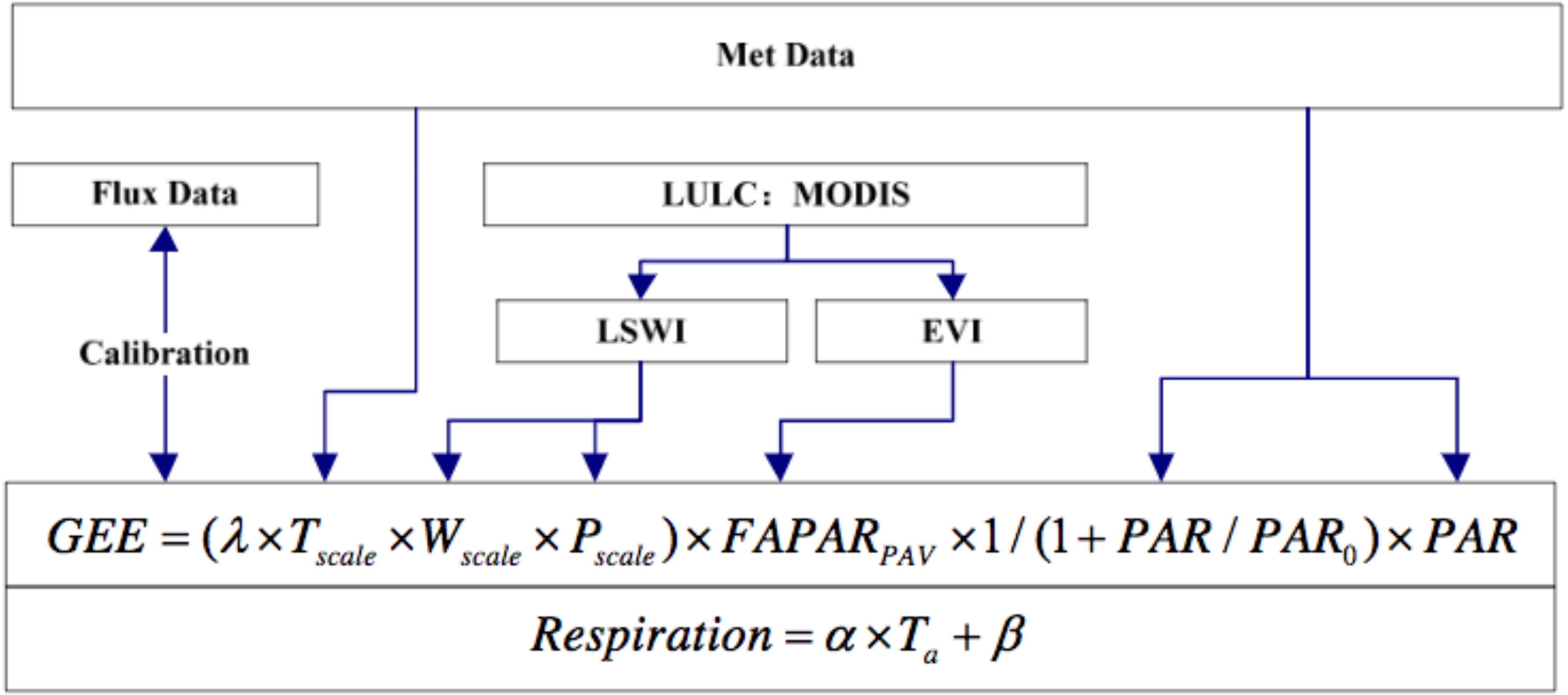


Fig. 3. Box-and-whisker plots for values of VPRM parameters, estimated monthly by plant functional type (PFT). Whiskers show 1.5 times the interquartile range. Units for parameters are as follows: λ: μmol $CO_2\,m^{-2}\,s^{-1}/\mu$mol PAR $m^{-2}\,s^{-1}$; α: μmol $CO_2\,m^{-2}\,s^{-1}\,{}^{\circ}C^{-1}$; β: μmol $CO_2\,m^{-2}\,s^{-1}$; PAR_0: μmol PAR $m^{-2}\,s^{-1}$.



Fraction of Photosynthetically Active Radiation absorbed by the photosynthetically active portion of the vegetation
FAPAR=EVI

Should we try **FAPAR=1.25*(EVI-0.1)**?

Compare with Ameriflux or ACT-America?