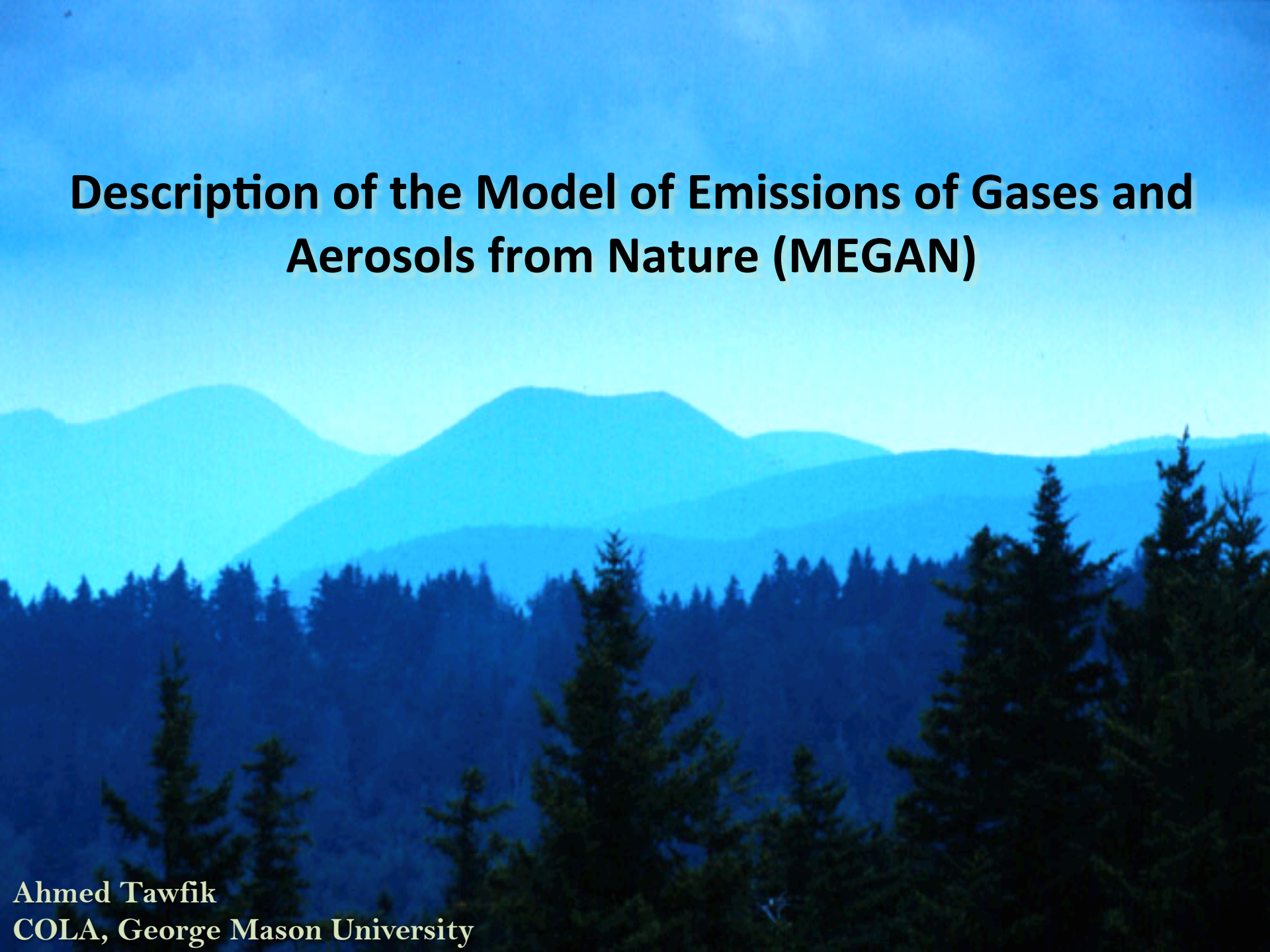
Description of the Model of Emissions of Gases and Aerosols from Nature (MEGAN)



Ahmed Tawfik
COLA, George Mason University

Overview

Background

- **What is MEGAN?** Briefly
- **Why model BVOCs?**

Practical

- **How MEGAN works**
- **MEGAN in CLM**
- **Applications**

Overview

Background

- **What is MEGAN?** Briefly
- **Why model BVOCs?**

Practical

- **How MEGAN works**
- **MEGAN in CLM**
- **Applications**

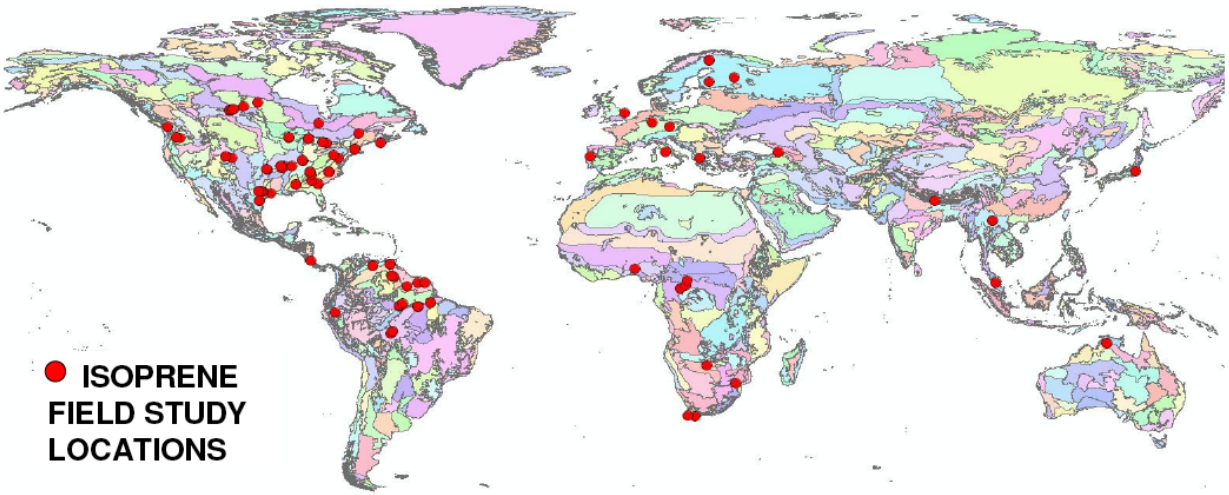
More Details:

Guenther et al. 2012: MEGAN2.1, Geosci. Model Dev. doi:10.5194/gmdd-5-1503-2012

Guenther et al. 2006: MEGAN 1.0, Atmos. Chem. Phys., doi:10.5194/acp-6-3181-2006

What is MEGAN?

- **MEGAN = Model of Emissions of Gases and Aerosols from Nature**
- **Estimates *NET* biogenic volatile organic compound (BVOC) emissions to the atmosphere**
- **Uses >80 enclosure studies and >90 field measurement studies to parameterize what controls emission rates**



(Guenther et al. 2006)

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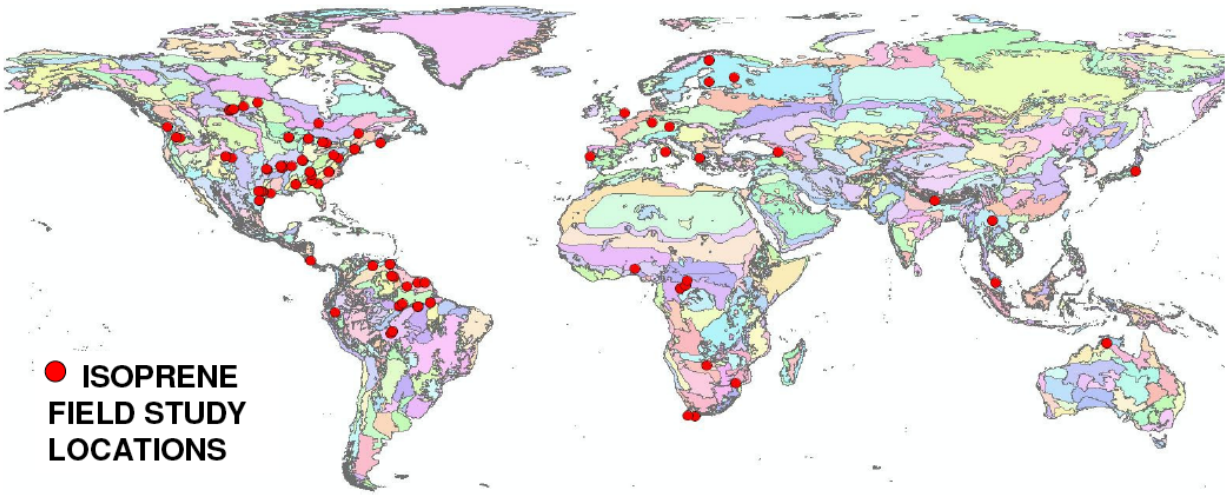

Why attempt to model BVOCs?

(Guenther et al. 2006)

Why Model BVOC Emissions?

+

+

= Ozone

Why Model BVOC Emissions?

Sunlight + Volatile Organics + Nitrogen Oxides = Ozone

hν + VOCs + NO_y = O_3

+

+

= Ozone

Why Model BVOC Emissions?

Sunlight + Volatile Organics + Nitrogen Oxides = Ozone

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Aerosols

+

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Why Model BVOC Emissions?

CO_2

Sunlight + Volatile Organics + Nitrogen Oxides = Ozone

hν + VOCs + NO_y = O_3

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+

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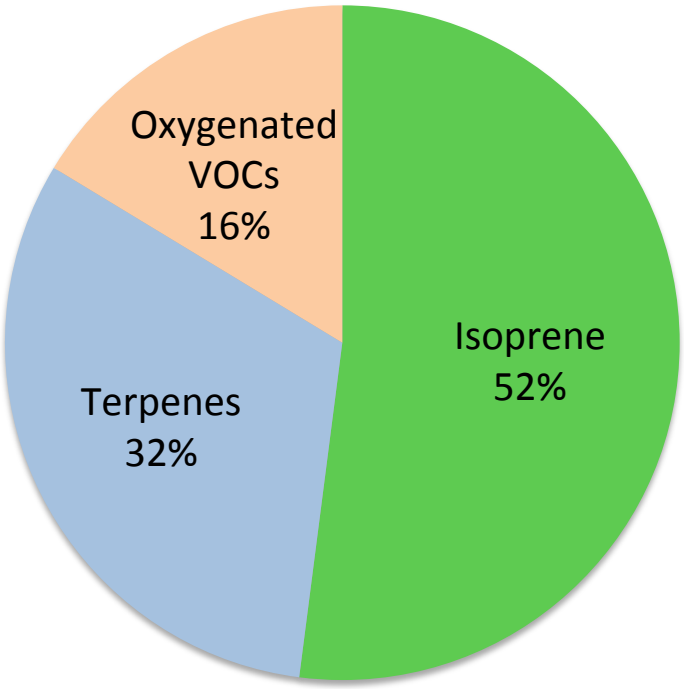
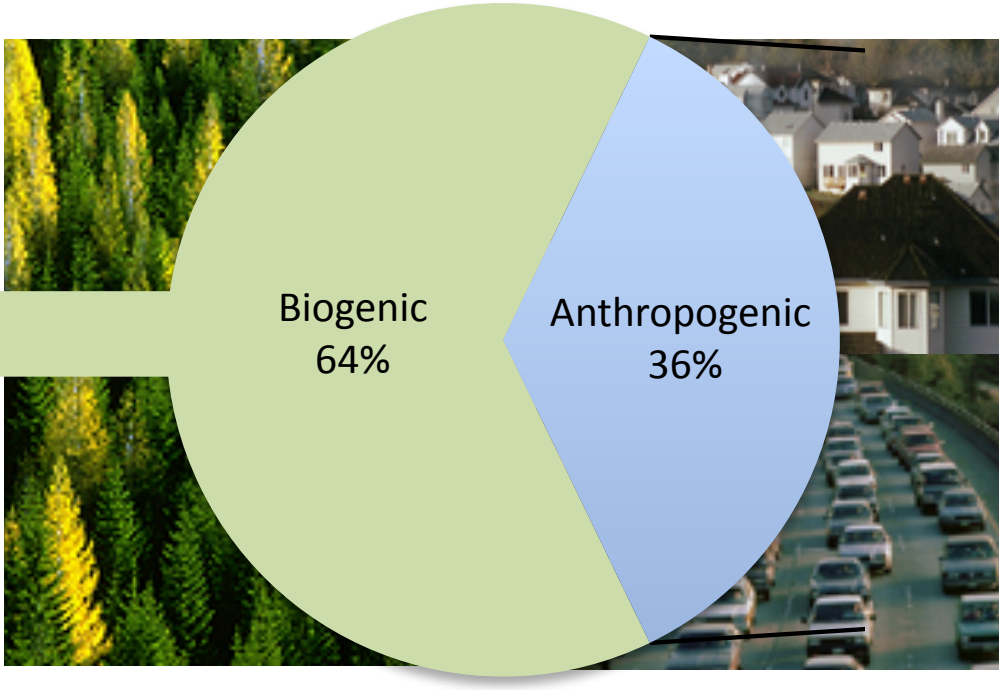
Sources of BVOCs

- The majority of VOCs come from natural (biogenic) sources
- Isoprene accounts for a majority of VOC reactivity

Percentages for US





(Source: EPA; Fuentes 2000)

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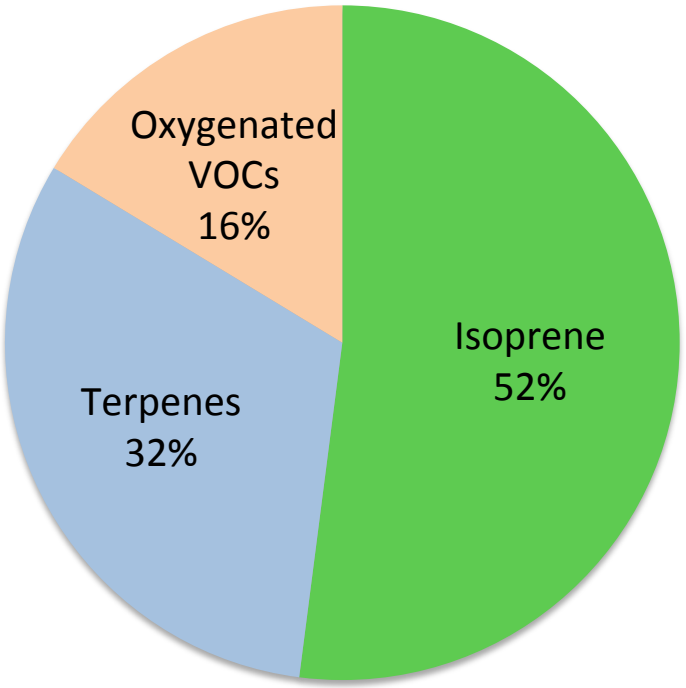

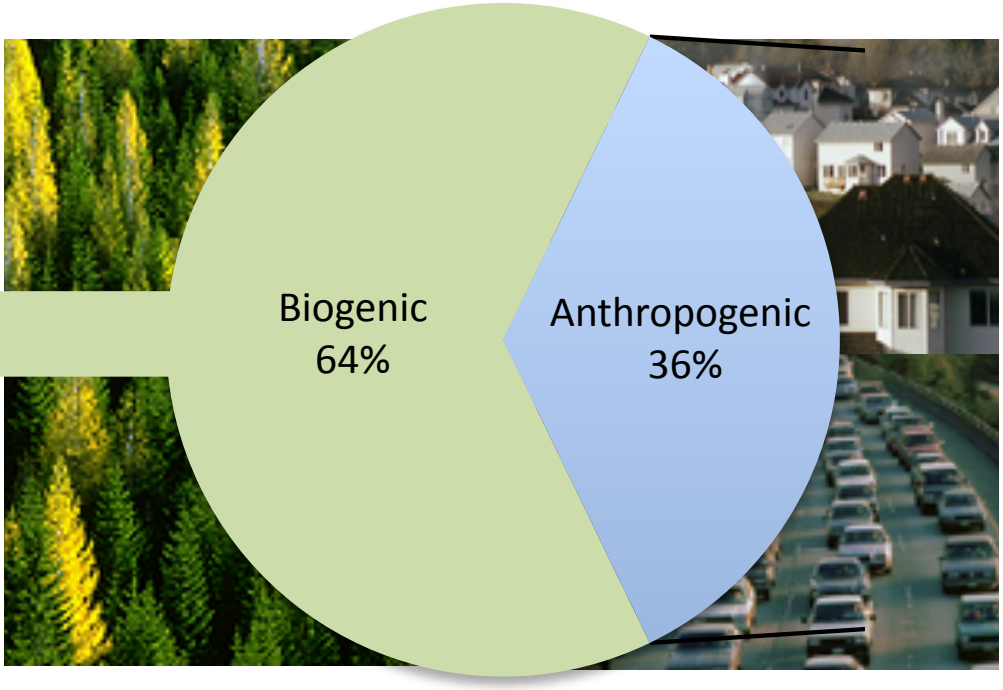

***** Biogenic VOC Emission highly depends on vegetation type and meteorology***

(Source: EPA; Fuentes 2000)

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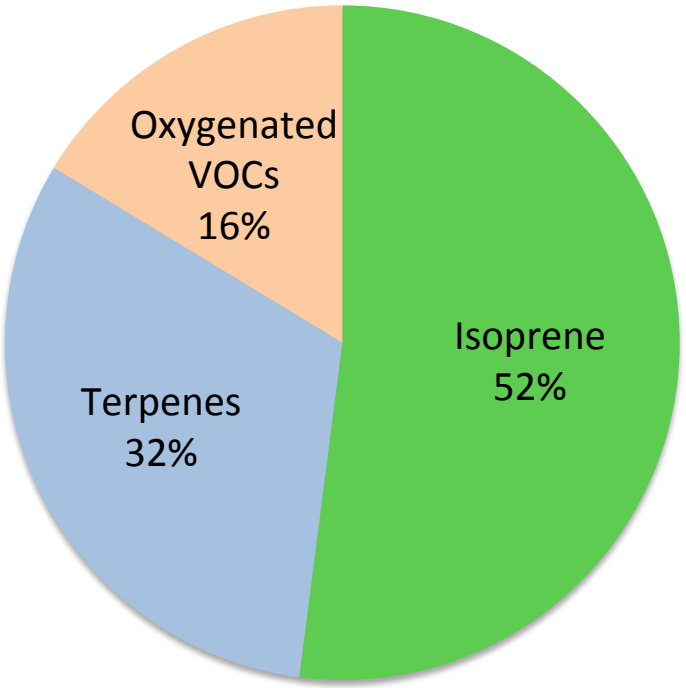
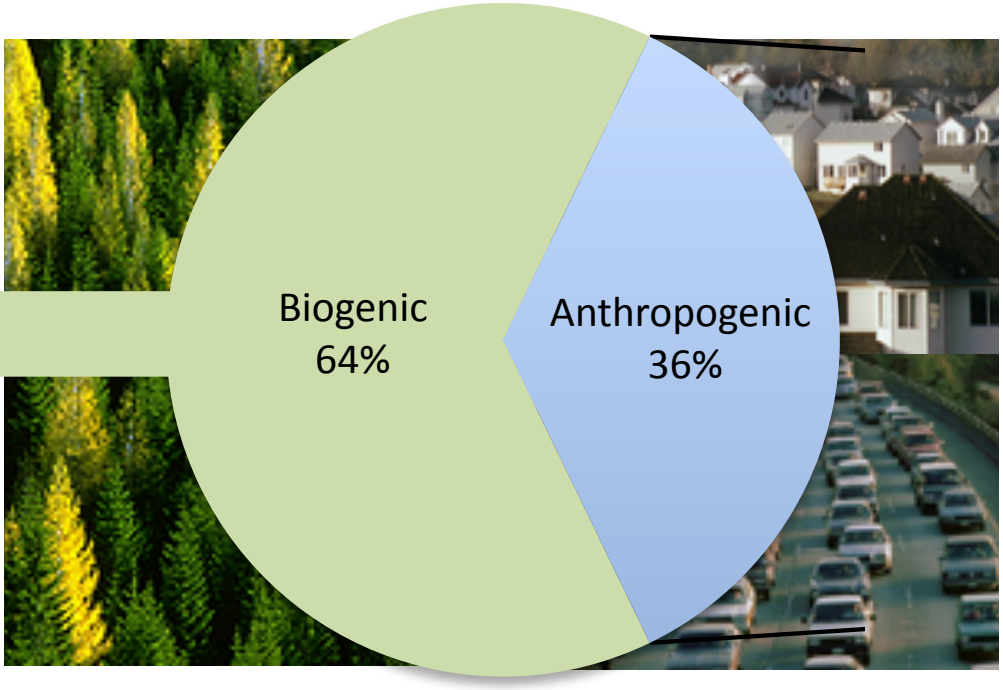


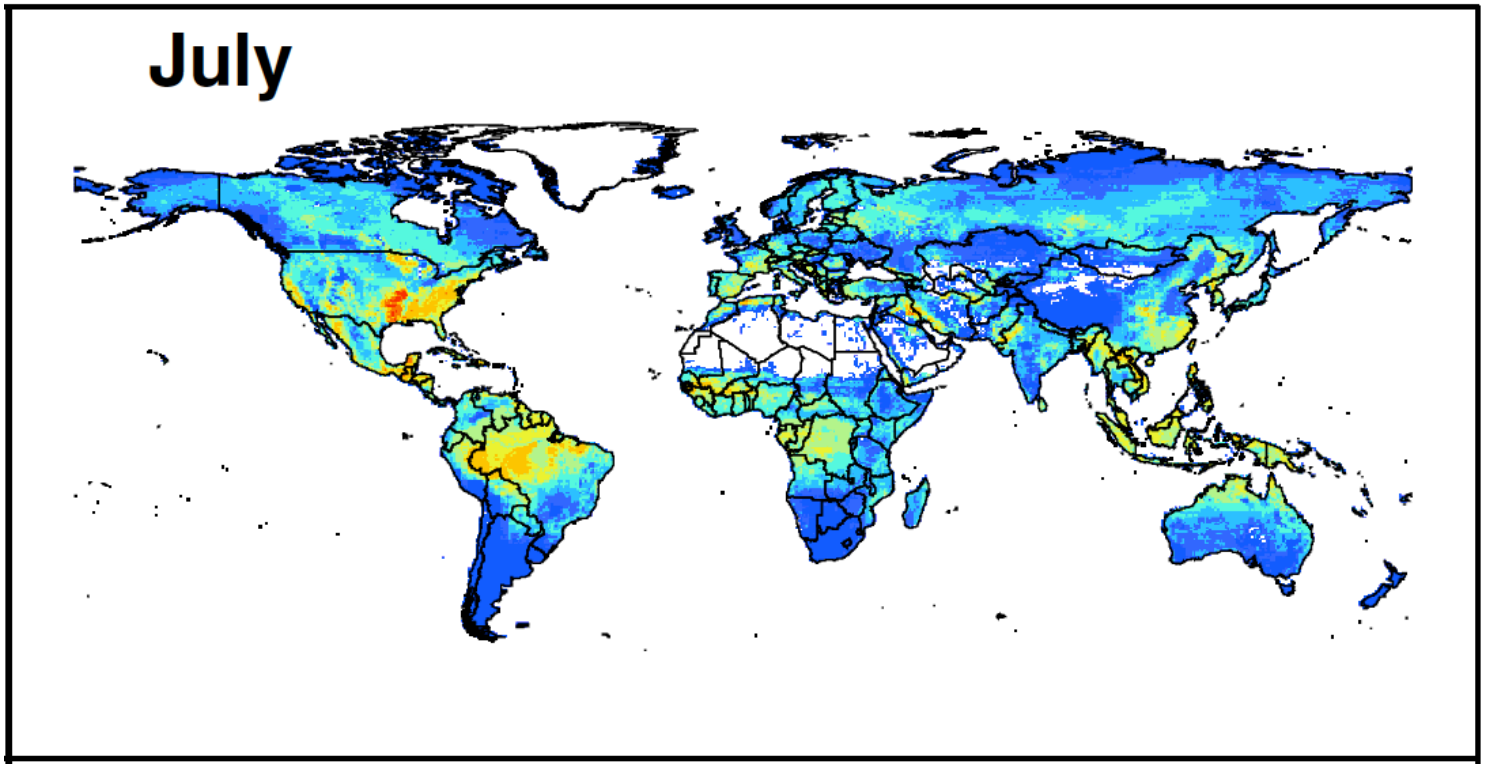


***** Biogenic VOC Emission highly depends on vegetation type and meteorology***

(Source: EPA; Fuentes 2000)

Global Contributions of BVOCs

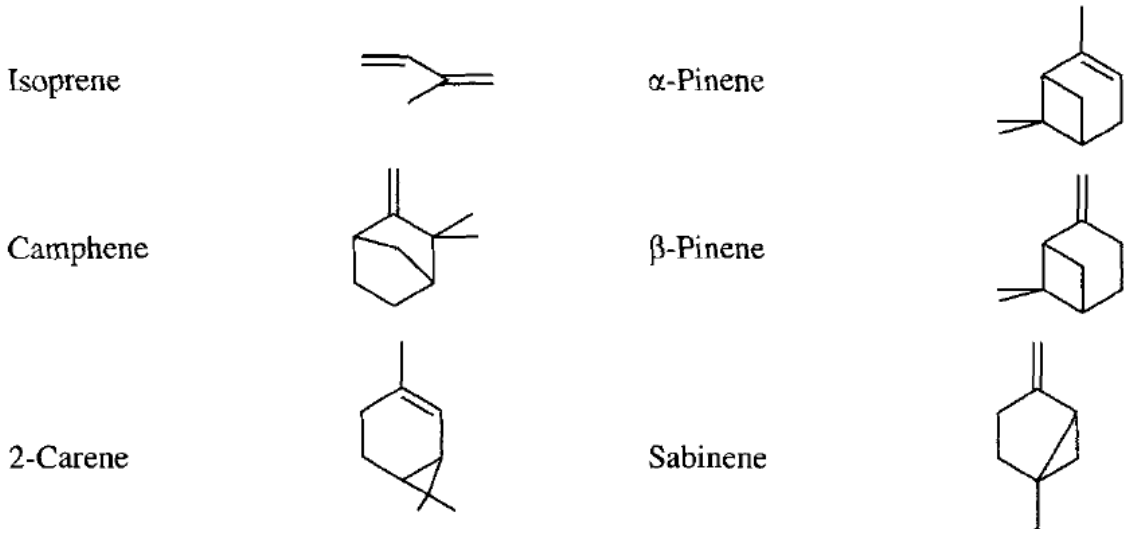
- **1-2% of carbon assimilated by the terrestrial ecosystem per year is emitted back to the atmosphere as BVOCs globally**
- **Can be much higher regionally under stressed conditions (~10%)**



(Guenther et al. 2006; Guenther et al. 2012)

Biogenic VOC Classes

- **There are several BVOC classes:**
  - **Isoprene** → **C_5H_8**
  - **Monoterpenes** → **2*isoprene**
  - **Sesquiterpenes** → **3*isoprene**
  - **Oxygenated VOCs** → **$C_xH_xO_x$**
- **BVOC classes have similar oxidation pathways in the atmosphere**



(Seinfeld and Pandis 2006)

Why Plants Emit VOCs

Plant protection against stress

Thermotolerance

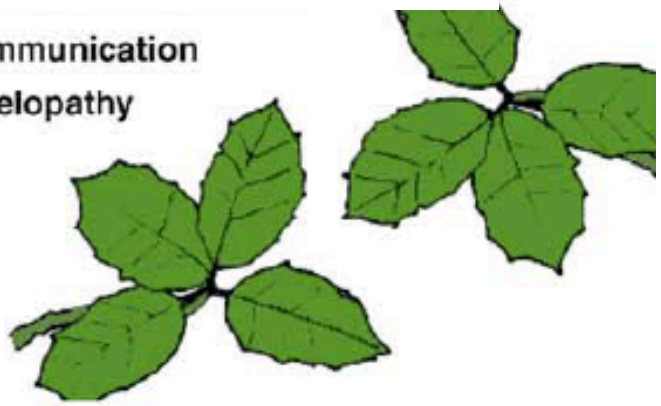
Oxidative stress tolerance

Photoprotection

Plant-Plant interaction

Communication

Allelopathy

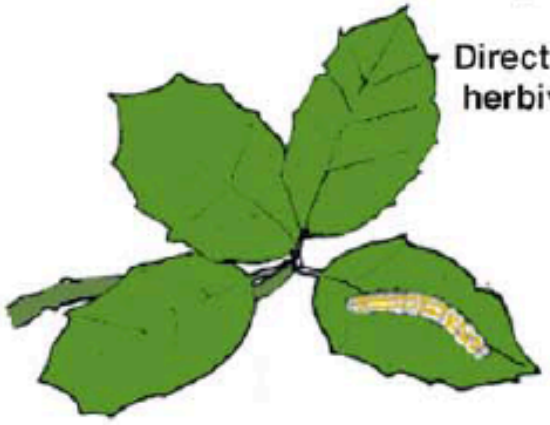


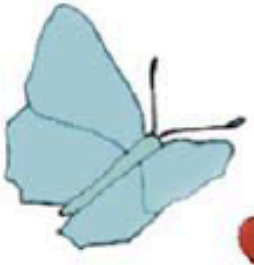
Plant defense

Indirect defense against herbivores

Direct defense against pathogens

Direct defense against herbivores





Plant Reproduction

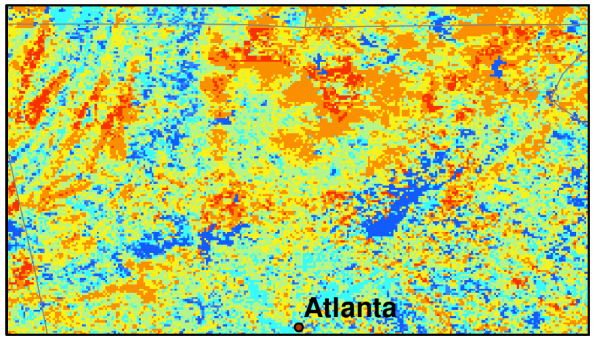
Pollination

Fruit and Seed dispersal

(Penuelas and Staudt 2010)

How MEGAN Models Emissions?

Modify a Standard Emission Factor (ε)



(Guenther et al. 2006)

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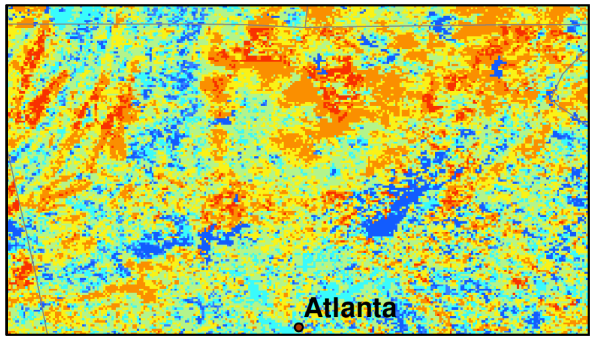


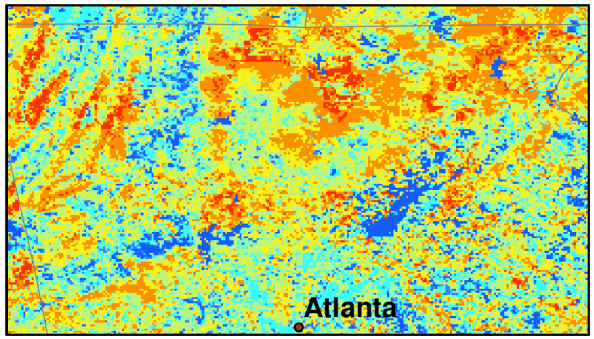
ε = emission rate for a specific environment condition

This standard emission factor is then modified by actual conditions to estimate an emission rate

(Guenther et al. 2006)

How MEGAN Models Emissions?

Modify a Standard Emission Factor (ε)



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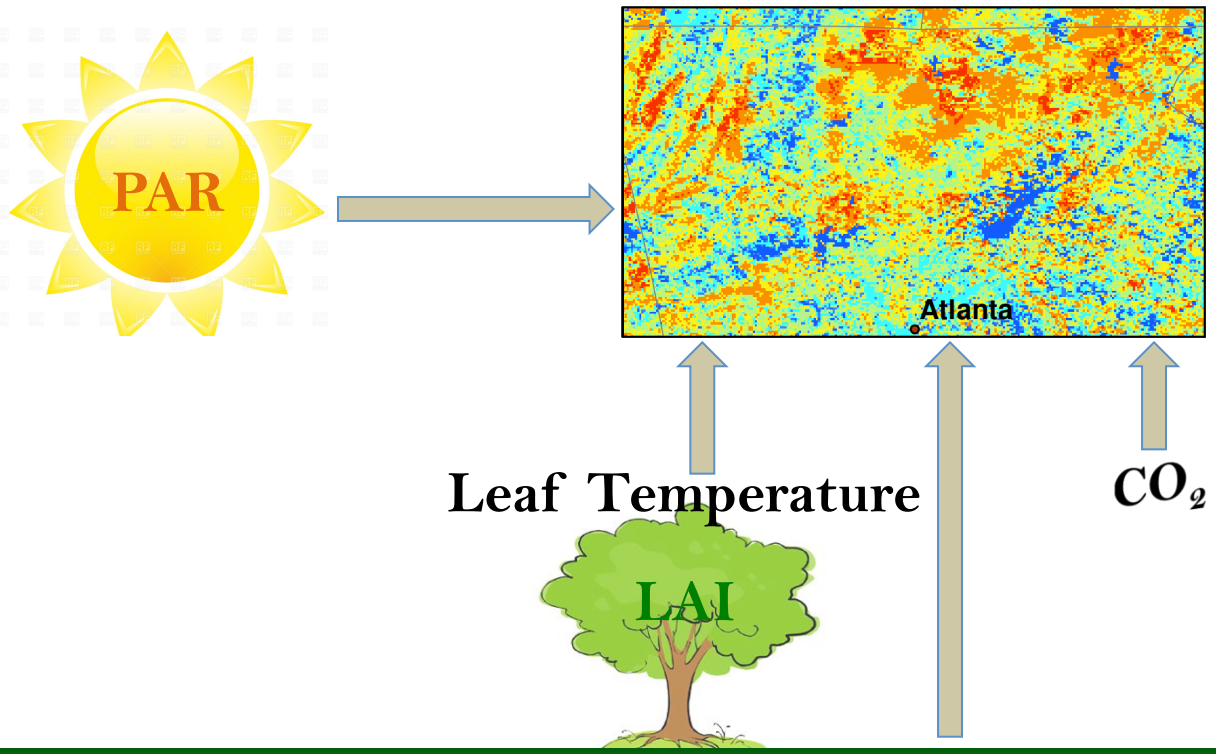
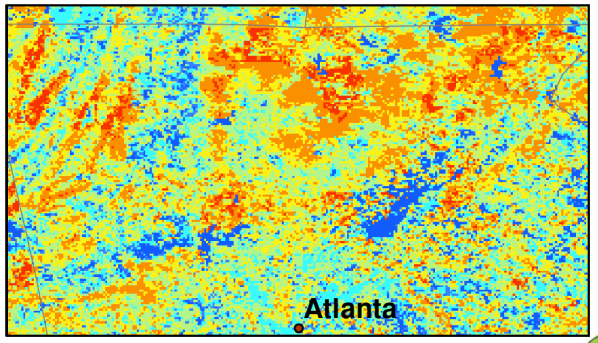


(Guenther et al. 2006)

How MEGAN Models Emissions?

Two ways of prescribing a Standard Emission Factor (ε)

Species-Specific Map



By PFT

CLM PFT Number	Description	Land Area	Isoprene Tg yr^{-1}	MT Tg yr^{-1}	Other Tg yr^{-1}
	Bare	40.7			
1	Needleleaf Evergreen Temperate Tree	5.46	1.61	7.38	13.2
2	Needleleaf Evergreen Boreal Tree	10.6	5.9	6.63	9.52
3	Needleleaf Deciduous Boreal Tree	1.46	0.0002	0.52	0.89
4	Broadleaf Evergreen Tropical Tree	15.6	244	82.9	127
5	Broadleaf Evergreen Temperate Tree	2.64	21.9	4.0	8.71
6	Broadleaf Deciduous Tropical Tree	12.9	178	45.0	74.3
7	Broadleaf Deciduous Temperate Tree	5.33	35.4	5.86	13.1
8	Broadleaf Deciduous Boreal Tree	2.14	4.79	0.99	2.02
9	Broadleaf Evergreen Temperate Shrub	0.18	0.23	0.08	0.33
10	Broadleaf Deciduous Temperate Shrub	4.15	21.8	6.77	16.4
11	Broadleaf Deciduous Boreal Shrub	9.33	2.93	1.07	3.3
12	Arctic C3 Grass	4.94	0.97	0.02	1.45
13	Cool C3 Grass	14.3	11.2	0.25	26.1
14	Warm C4 Grass	13.2	5.93	0.49	51.3
15	Crop1	16.3	0.02	0.36	44.5
	Total (all PFTs)	159	535	162	390

(Guenther et al. 2006; Guenther et al. 2012)

How MEGAN Models Emissions?

Two ways of prescribing a Standard Emission Factor (ε)

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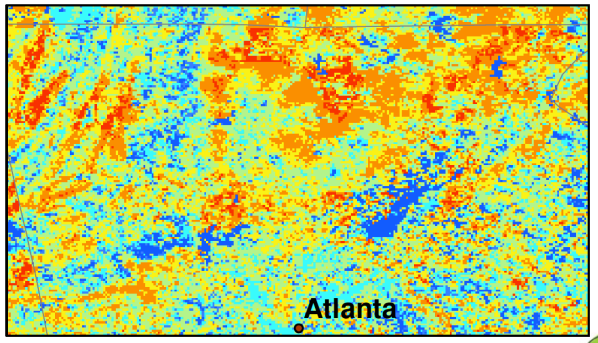

** Only for Isoprene in CLM

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MEGAN Algorithm

Emission Flux = $\varepsilon * LAI * C_E * \gamma_T * \gamma_{PAR} * \gamma_{age} * \gamma_{SM} * \gamma_{CO2} * \rho$

Input

MEGAN Calculation

** Each Gamma Factor (γ) has a response curve derived from observations

(Guenther et al. 2006; Guenther et al. 2012)

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Input	MEGAN Calculation
Photosyn. Active Radiation	γ_{PAR}
Leaf Temperature	γ_T
CO2	γ_{CO2}
Soil Moisture	γ_{SM}
Leaf Area Index	LAI
Standard Emission Factor	ε
Consistency Factor	C_E
In-canopy Reactivity	ρ

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CO_2	γ_{CO2}	
Soil Moisture	γ_{SM}	= 1
Leaf Area Index	LAI	
Standard Emission Factor	ε	
Consistency Factor	C_E	
In-canopy Reactivity	ρ	= 1

** Each Gamma Factor (γ) has a response curve derived from observations

(Guenther et al. 2006; Guenther et al. 2012)

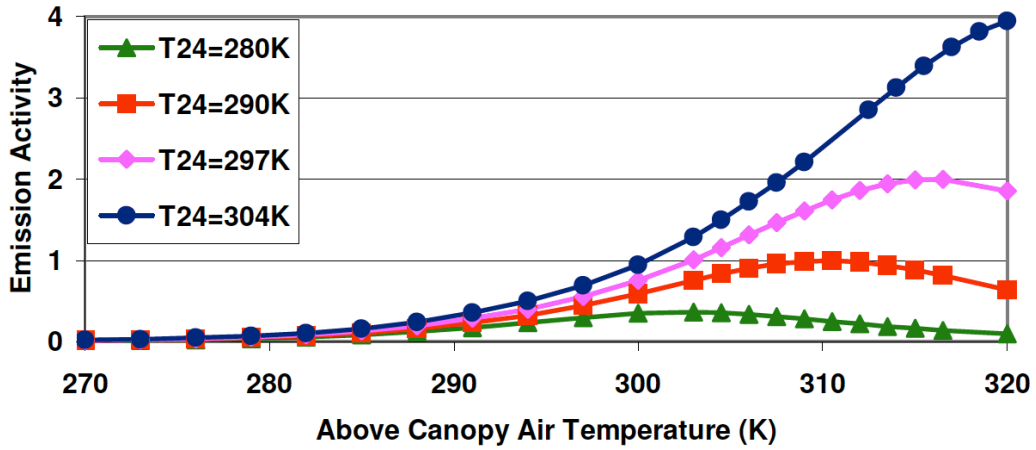
List of BVOCs Estimated by MEGAN

Compound Class
Isoprene
Myrcene
Sabinene
Limonene
3-Carene
t-β-Ocimene
β-Pinene
α-Pinene
Other Monoterpenes
α-Farnesene
β-Caryophyllene
Other Sesquiterpenes
232-MBO
Methanol
Acetone
CO
Bidirectional VOC
Stress VOC
Other VOC

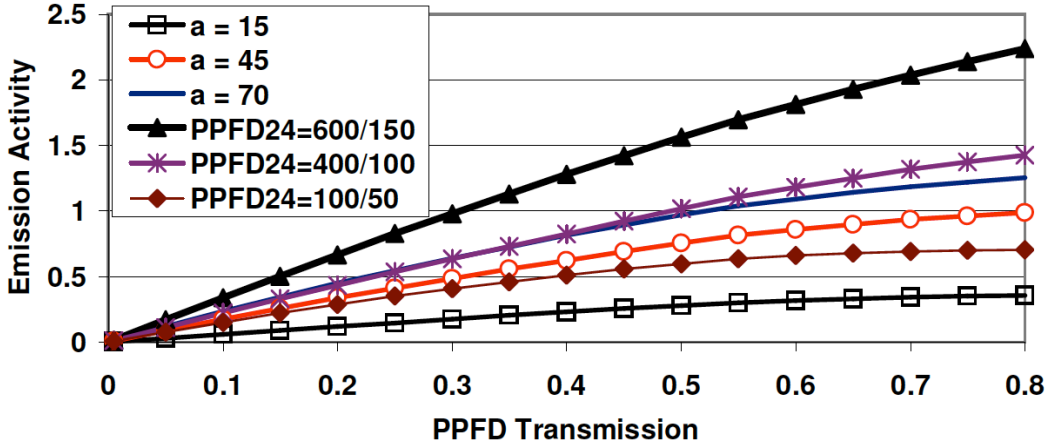
(Guenther et al. 2006; Guenther et al. 2012)

Sensitivity to Different Gamma Factors

- Emissions increase rapidly with temperature
- γ_T also captures past 24 and 240 hour effects



- PAR response is more gradual
- Also captures past PAR conditions

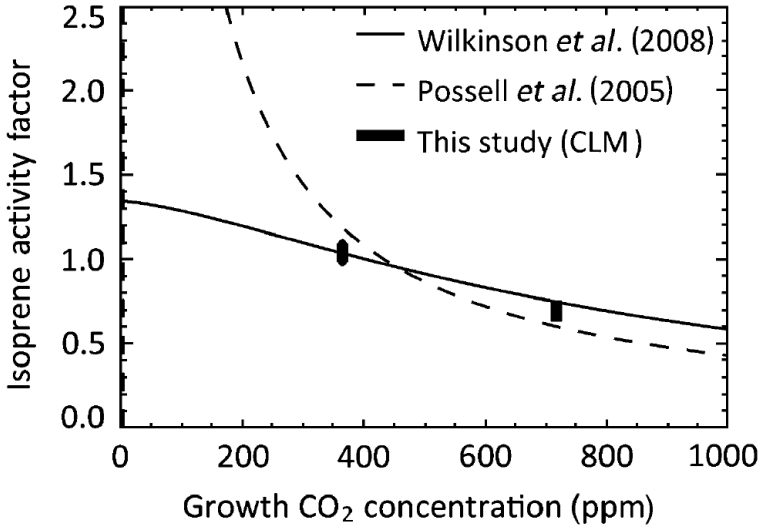


- γ_T and γ_p account for shaded and sunlit canopy fraction

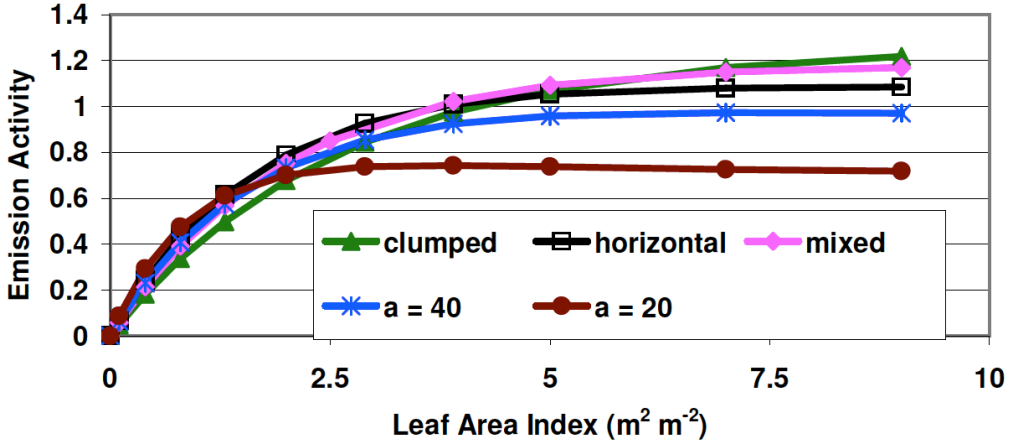
(Guenther et al. 2006)

Sensitivity to Different Gamma Factors

- CO2 emissions suppress BVOC emissions
- Only included for isoprene; =1 for all other



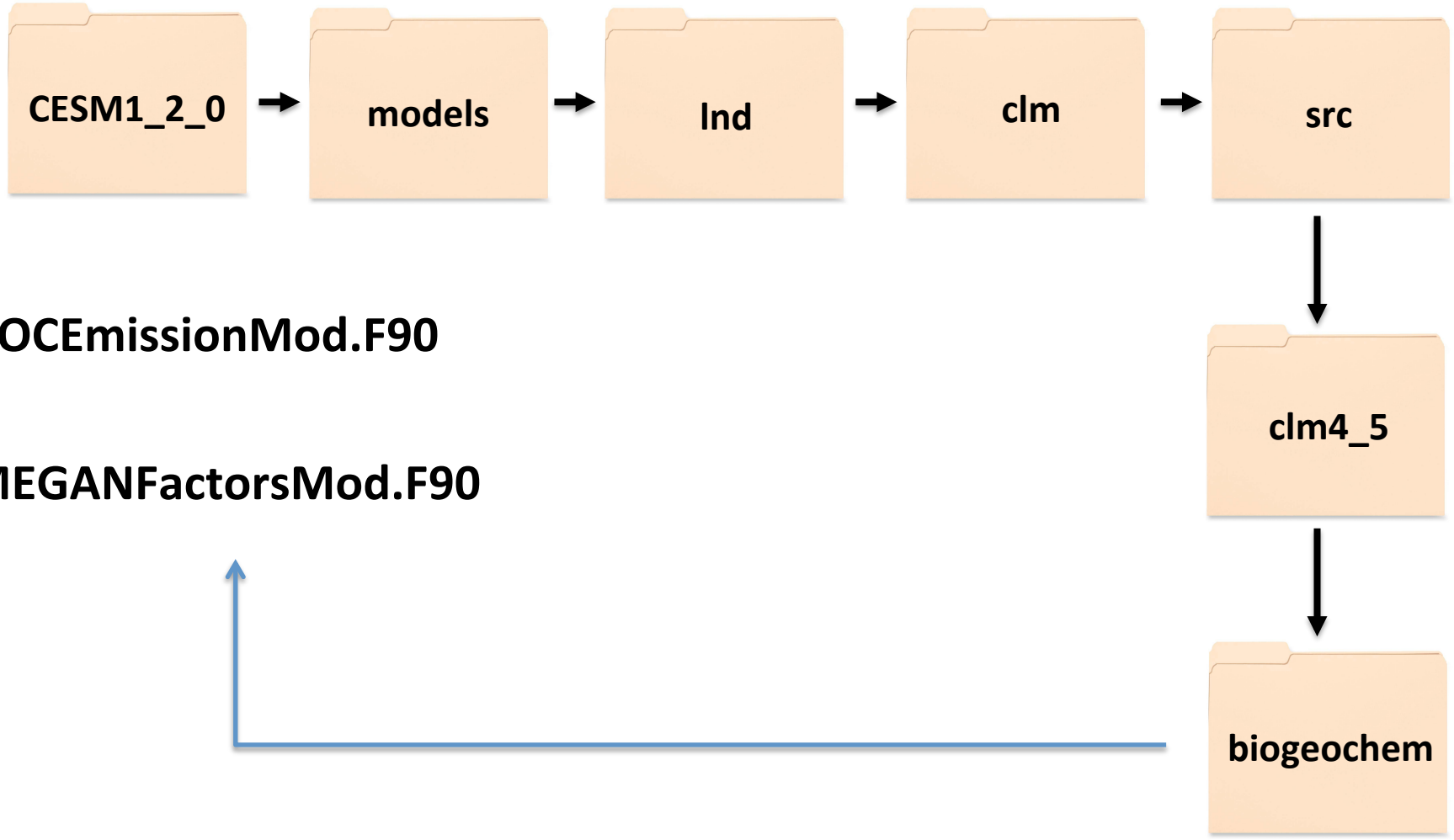
- More LAI equals more emissions to a point
- Note that activity factor is rarely above 1



(Guenther et al. 2006; Heald et al. 2009)

Where does MEGAN live in the CESM?

cesm1_2_0/models/lnd/clm/src/clm4_5/biogeochem



VOCEmissionMod.F90

MEGANFactorsMod.F90

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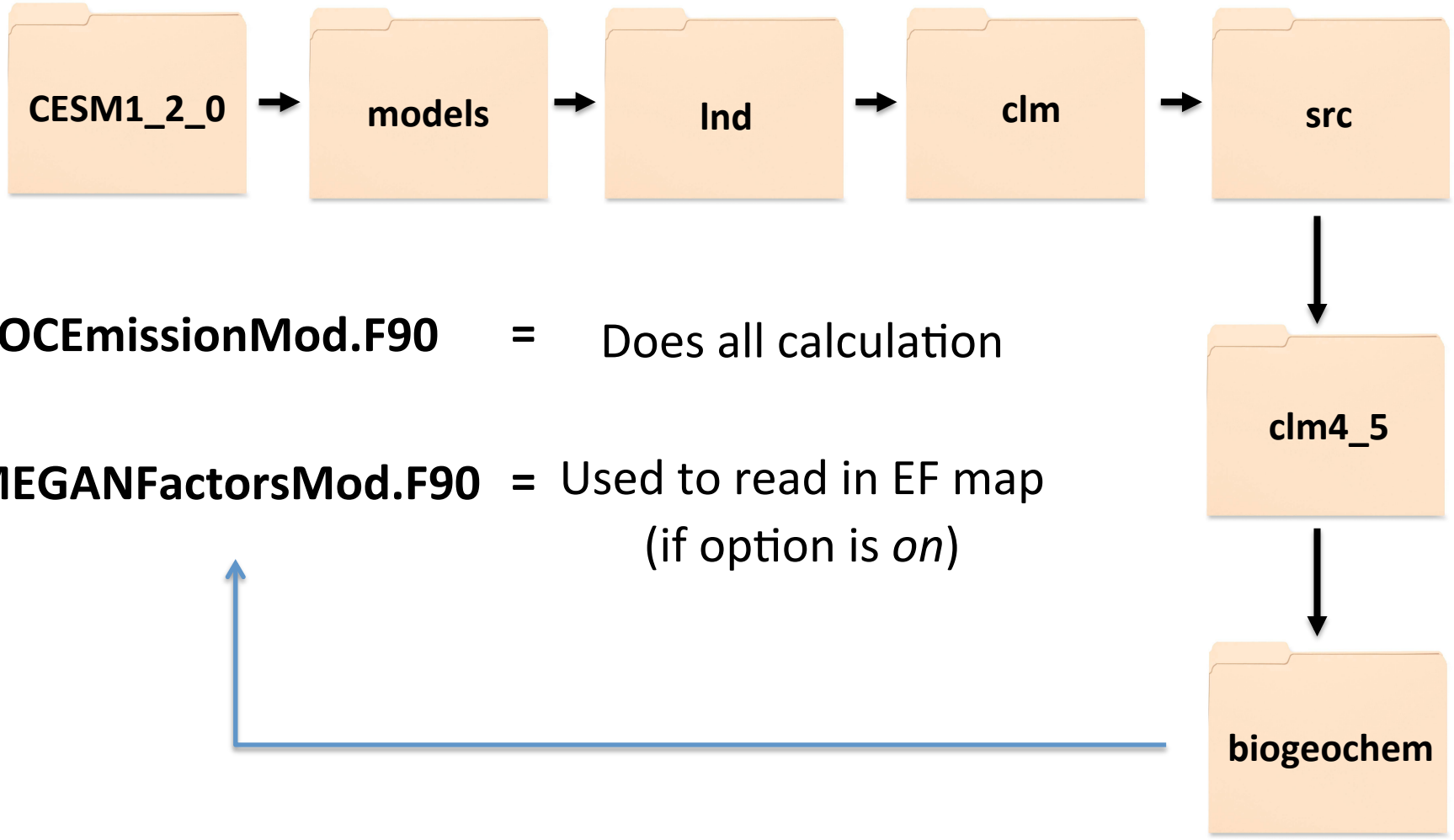


VOCEmissionMod.F90 = Does all calculation

MEGANFactorsMod.F90 = Used to read in EF map (if option is *on*)

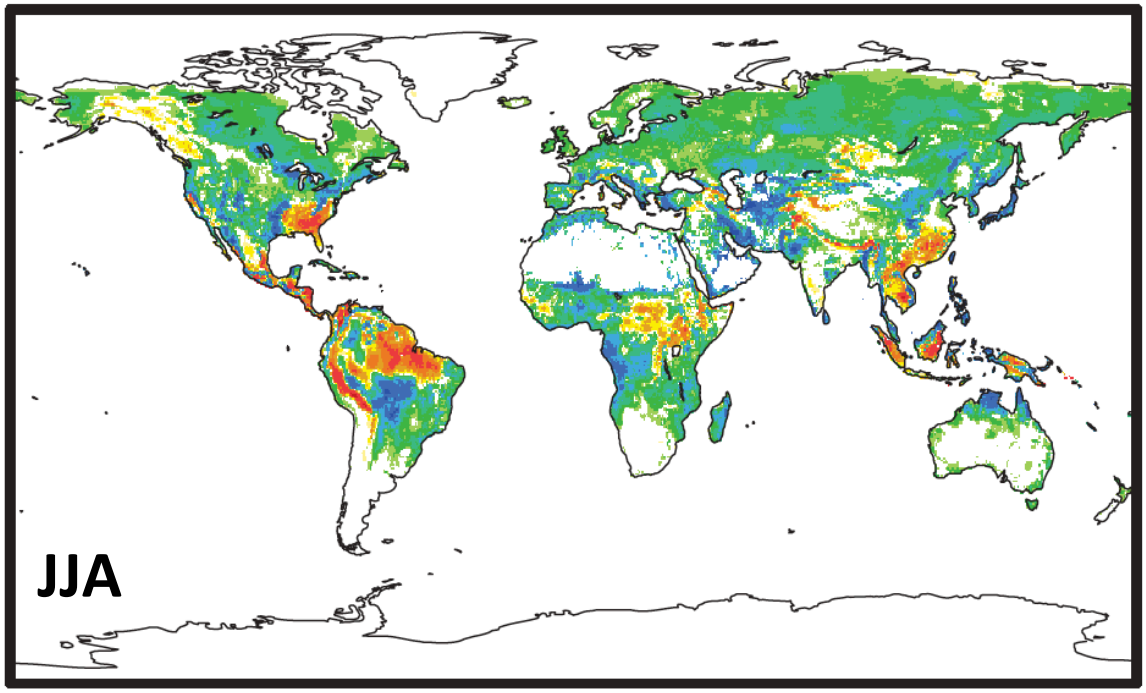
MEGAN Workflow in VOCEmissionMod

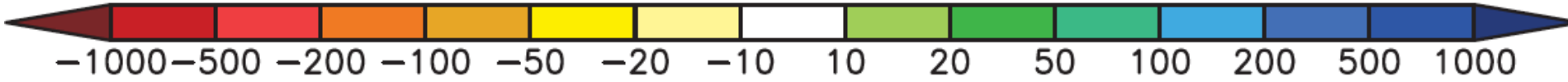
1. Initialize variables
2. Read EF map (for isoprene only) if user wants otherwise use PFT
3. Loop over all vegetation types
   - Calculate all the gamma factors based CLM forcing
   - Scale the standard EF by the gamma factor to get emissions
4. Send to CAM/Chemistry model if running coupled

Sensitive to Forcing Data

Only changing the meteorological forcing dataset

NCEP minus CRU





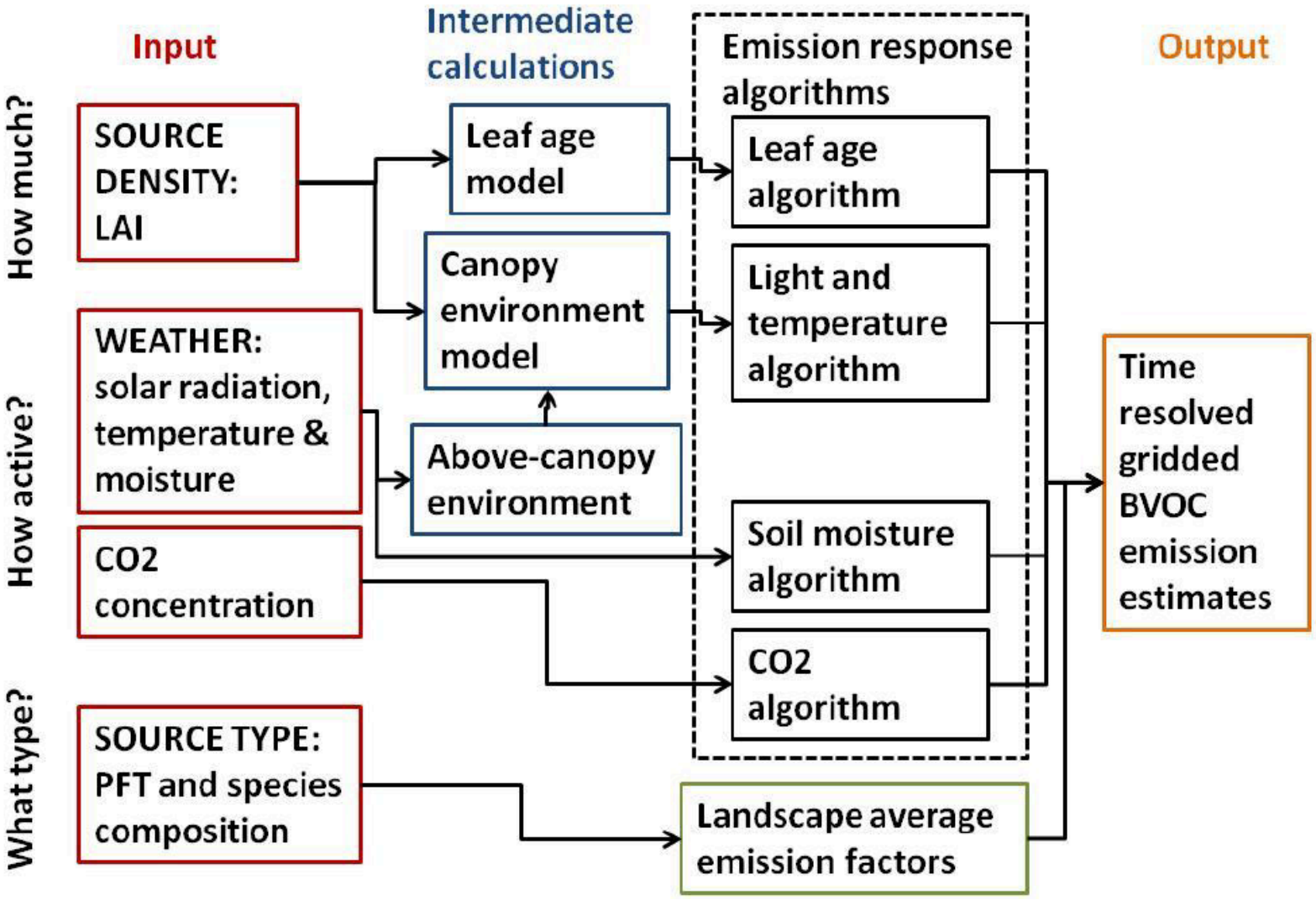
mg C m^{-2} per month

(Arneth et al. 2011)

Applications of MEGAN

- Estimate global or regional carbon "lost" to the atmosphere
- Implement with CAM and atmospheric chemistry to understand impacts of BVOCs on
  - Aerosol-cloud feedbacks
  - Ozone air quality
  - Direct radiative forcing
- Influence of changing land cover type
- Emissions changes under different future projections

Summary of MEGAN



(Guenther et al. 2006; Guenther et al. 2012)