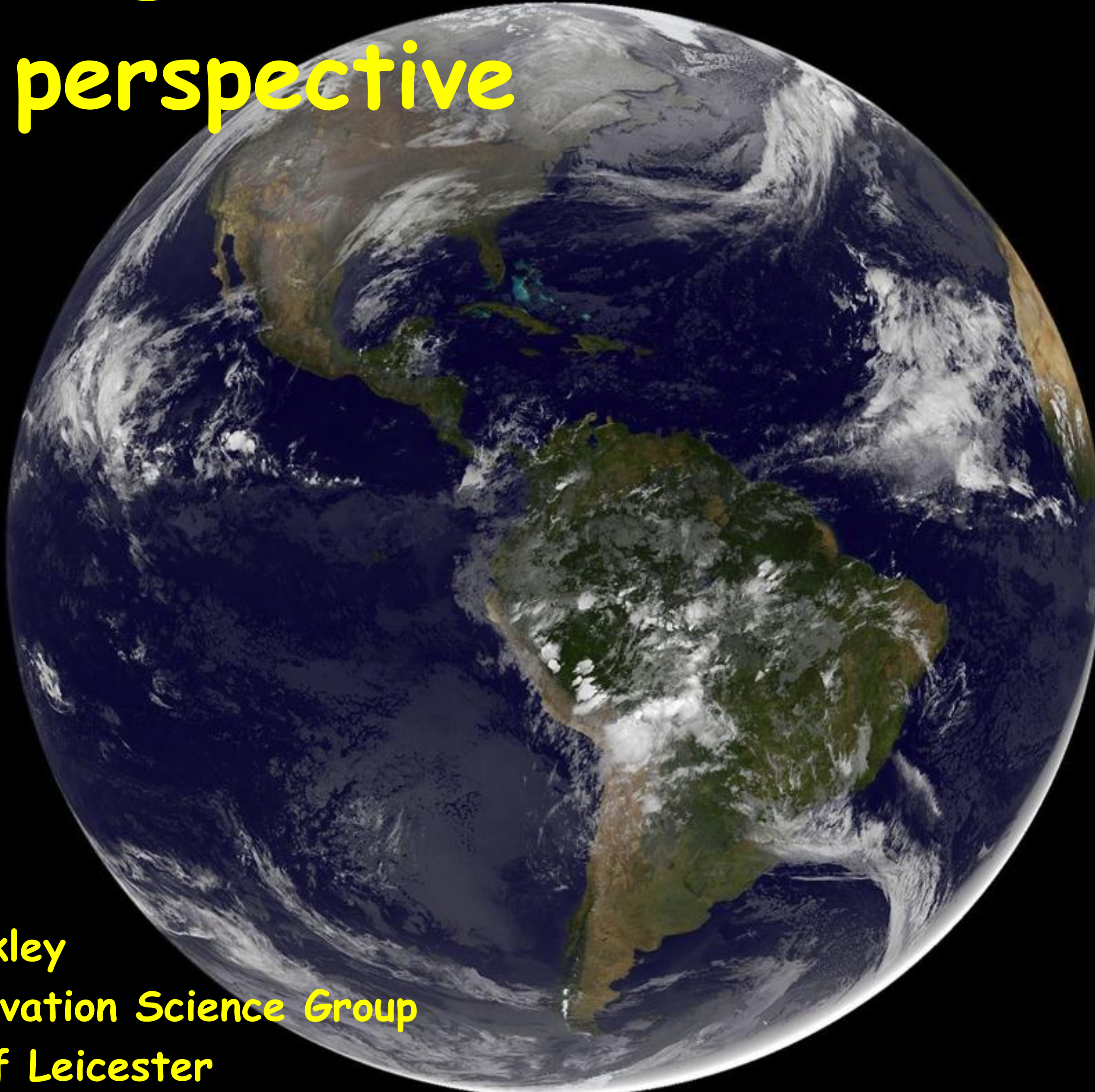
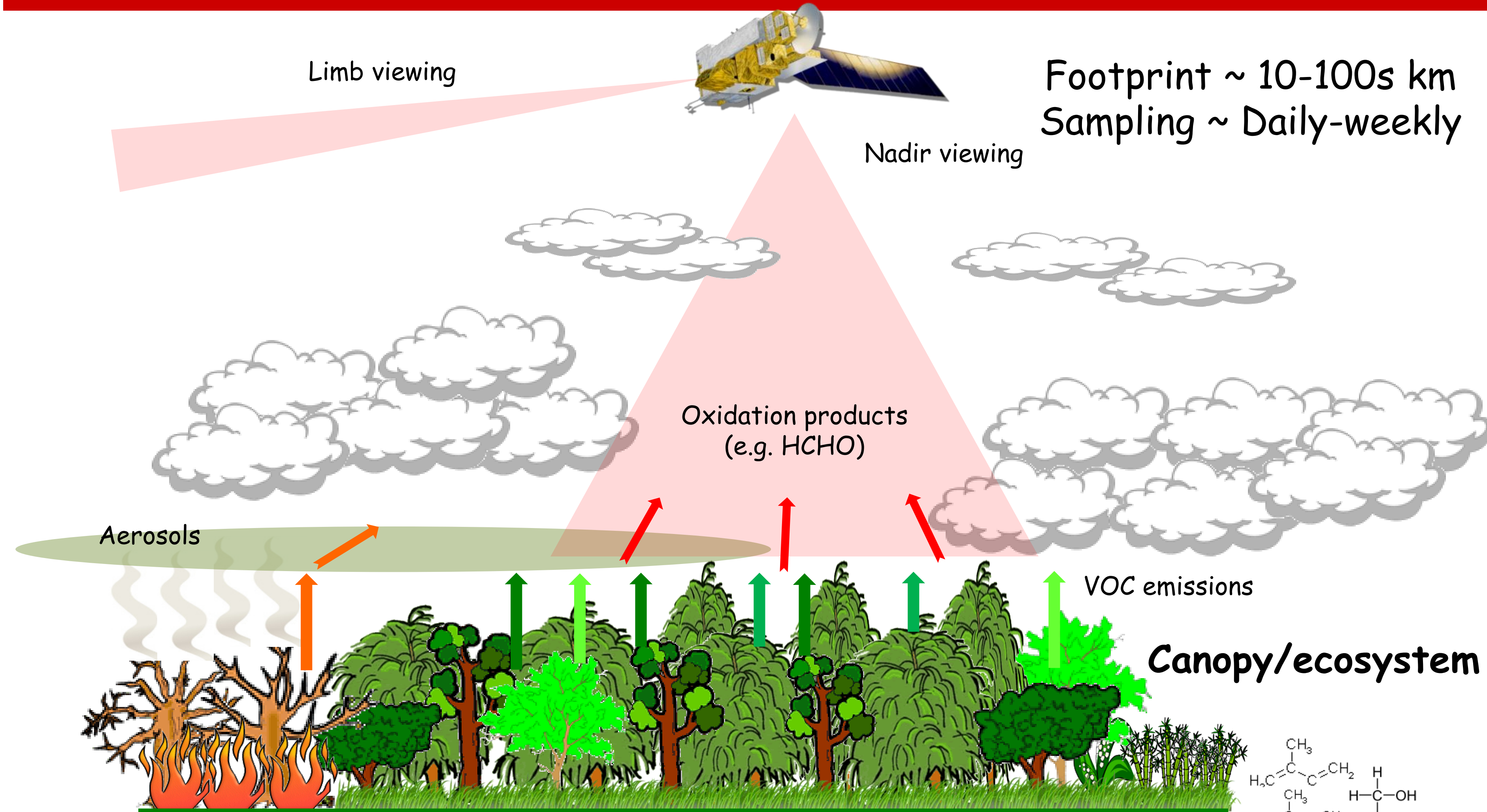
Observing the Amazon from Space: A UK perspective

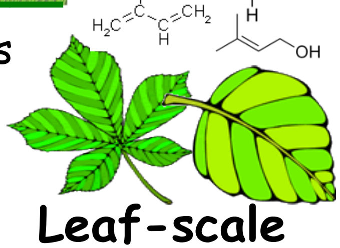


Michael Barkley
Earth Observation Science Group
University of Leicester

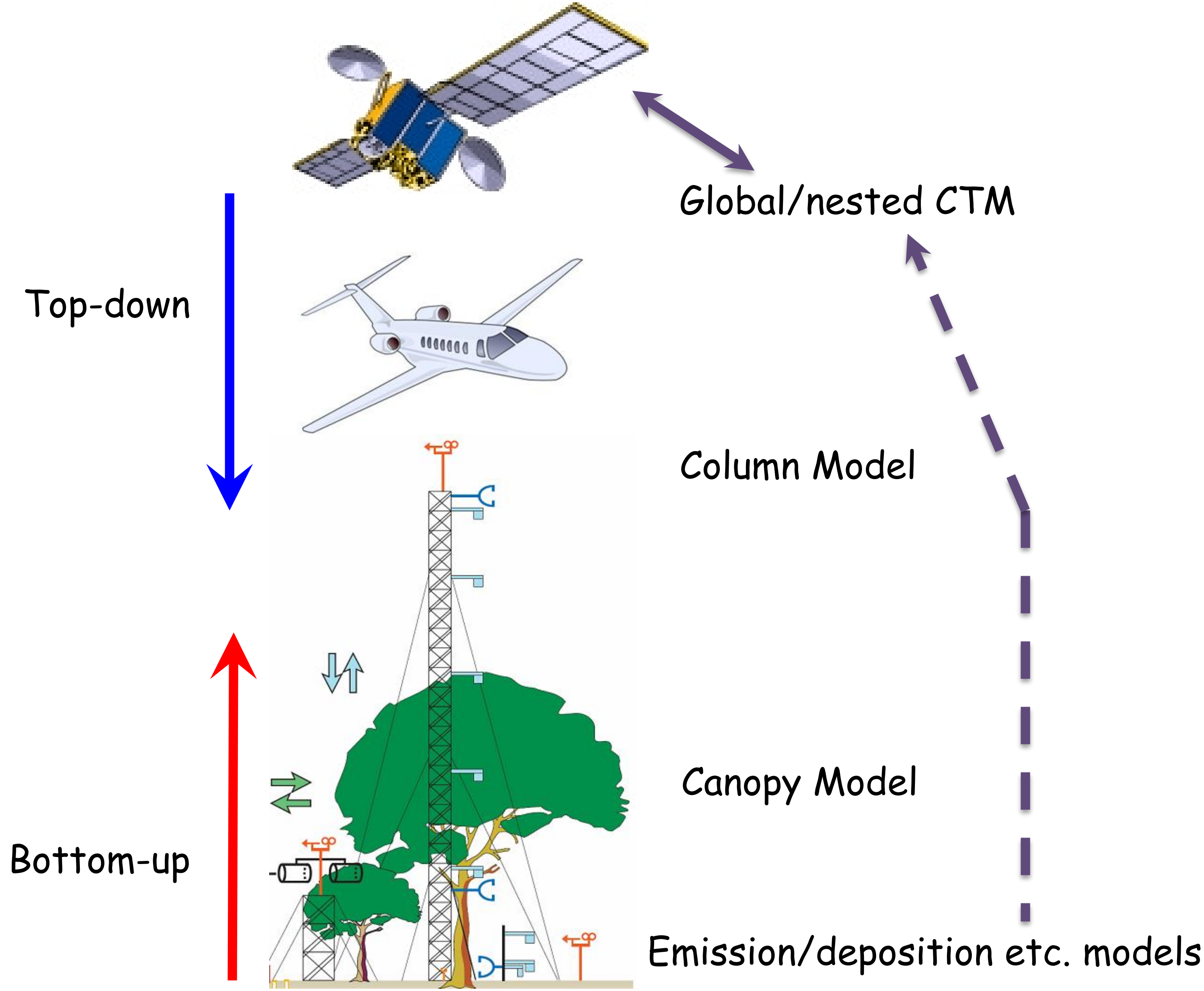
Atmospheric remote sensing over rainforests



- Information on ecosystem/regional/continental photochemistry and fluxes
- Specific localized events (e.g., fire)
- Long-range transport (influx and outflow)
- Vertical transport/mixing



An integrated observing/modelling system

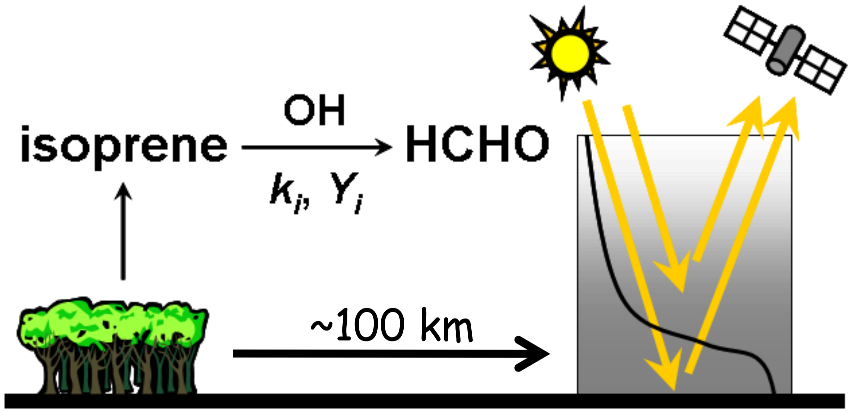


UK trace gas/aerosol/cloud retrievals

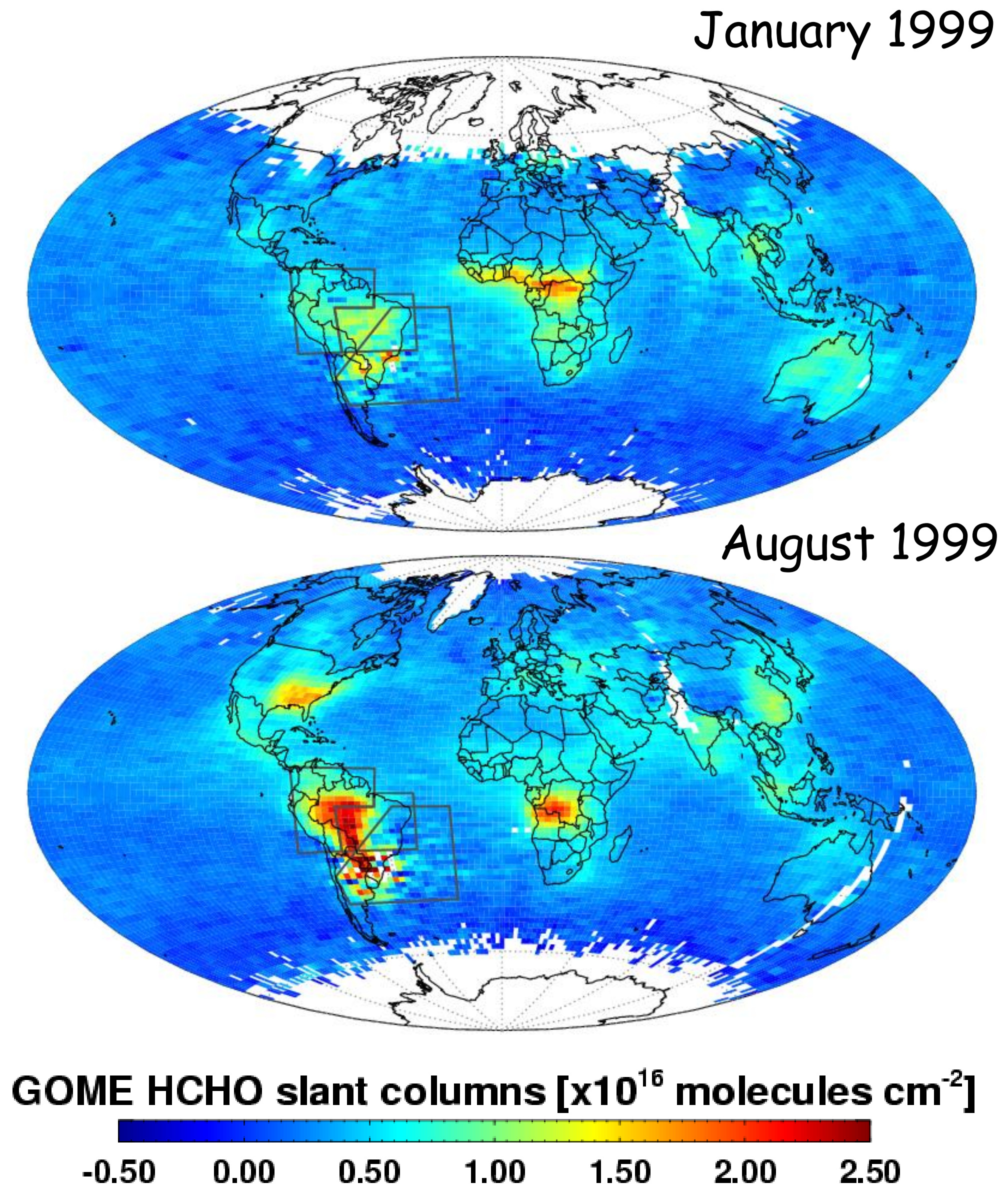
- National Centre for Earth Observation – Atmosphere Theme
  - List not exhaustive; other non-NCEO retrievals exist

Group	Satellite(s)	Product	Profile/Column
U. Leicester	GOSAT/SCIAMACHY	CO_2, CH_4	Total Columns
	GOME-2	HCHO CHOCHO	Tropospheric columns
	IASI	CO/organics	Columns
	MIPAS	Organics (e.g., PAN, acetone, formic acid)	Profiles (UT/LS)
RAL	GOME-2	Ozone	Tropospheric / total columns
	IASI	SO2, CH_4	Total columns
U. Oxford	MIPAS	p & T, H_2O, O_3, HNO_3, CH_4, N_2O, NO_2 CFC-11, CFC-12, $ClONO_2$, N_2O_5 and CO.	Profiles (UT/LS)
	AATSR (ORAC) (with RAL)	Aerosol (AOD, R_{EFF}, type) Surface albedo (550,660,870,1600 nm)	-
		Cloud (top-height & pressure, optical depth, T, ice/water path, phase, R_{EFF})	-
U. York	ACE	+18 species plus, T & P	Profiles (UT/LS)

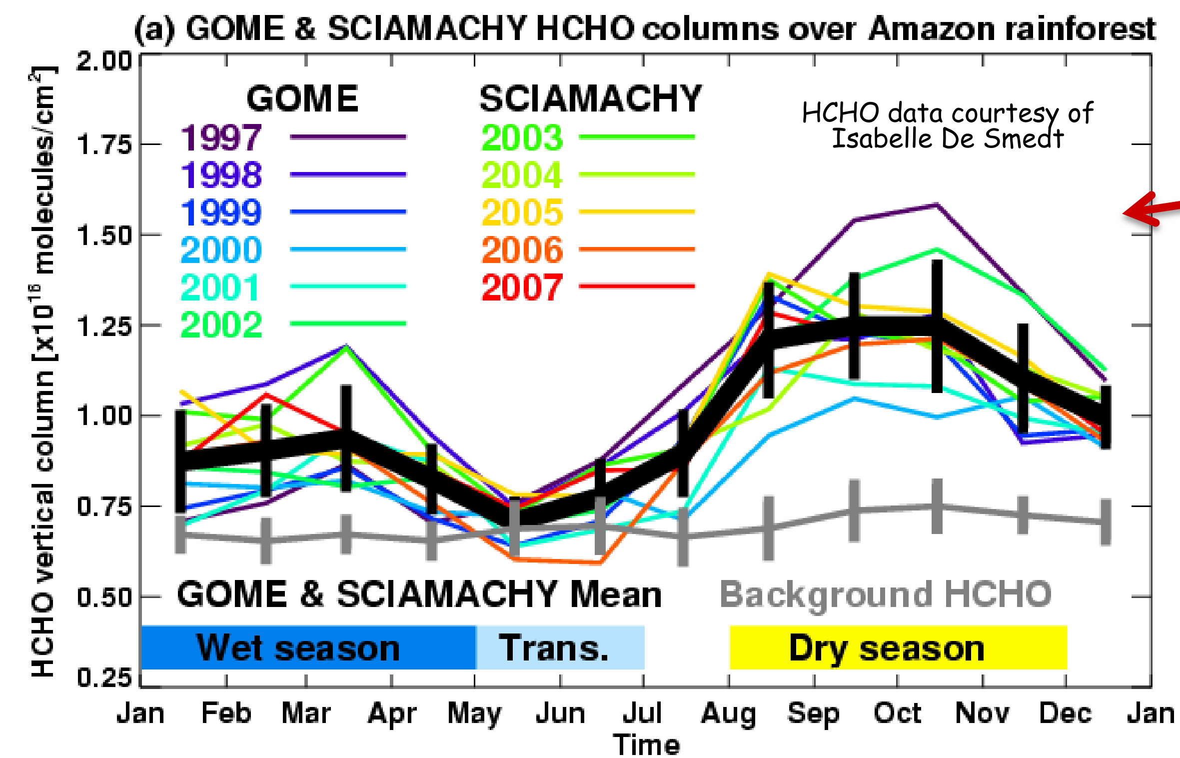
Mapping isoprene emissions from space using HCHO

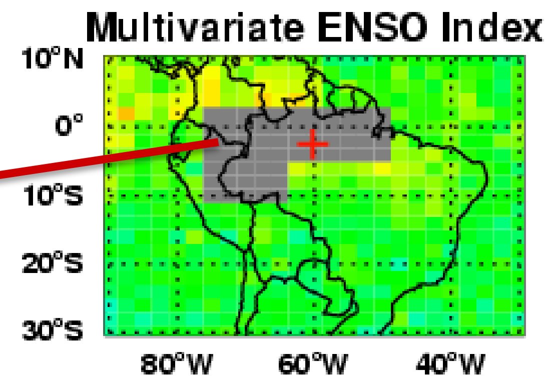


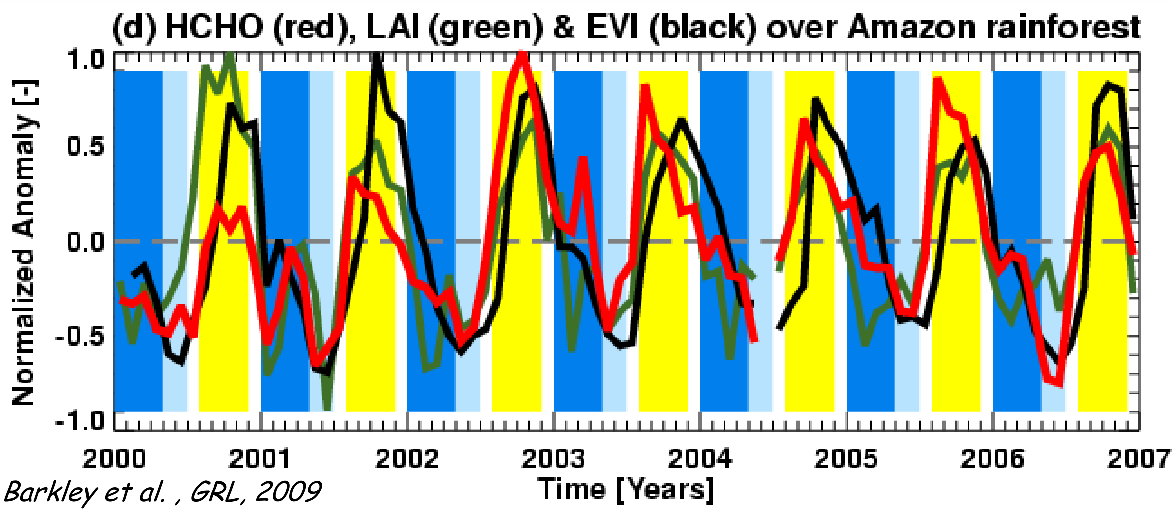
- Formaldehyde is a high-yield product of isoprene oxidation
- Isoprene emissions are the main driver of variability in observed HCHO columns
- Must use a chemistry-transport model (CTM) to invert HCHO columns to 'get' the top-down isoprene emission estimates



Unusual seasonal variation of HCHO columns



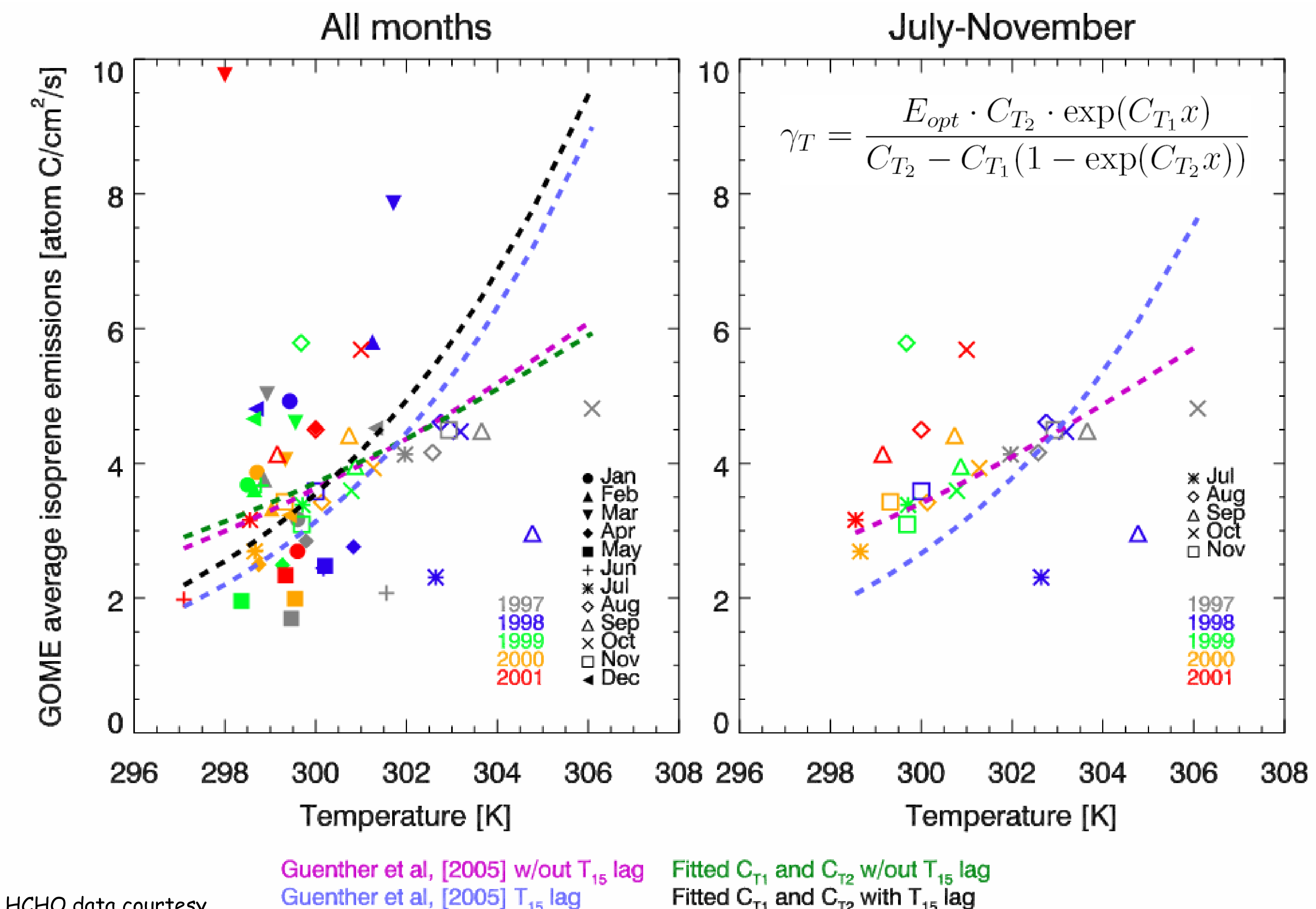




Barkley et al. , GRL, 2009

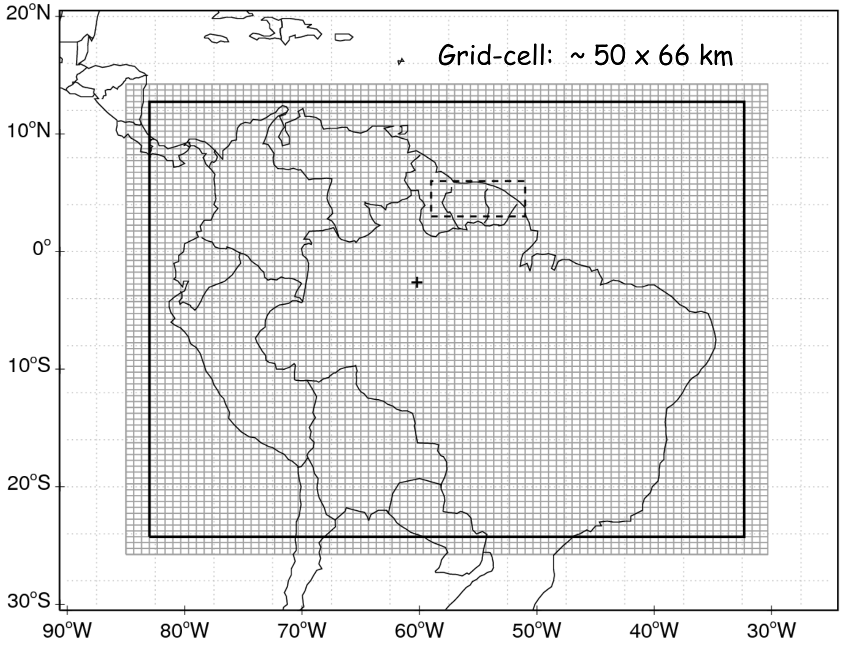
- Long-term HCHO seasonal cycle shows unexpected low columns during wet-to-dry transitional period
  - Fire scenes are excluded using firecounts & NO_2 columns
- HCHO oscillates in phase with vegetation
  - Majority of isoprene emitting species undergo leaf flushing (new leaf growth) prior to dry season in anticipation of light-rich conditions

Can we learn anything from the top-down estimates?



HCHO data courtesy of Kelly Chance

The GEOS-Chem Amazon nested grid



- Use CTM to produce ensemble of top-down isoprene emission estimates
  - Using different sensors, model settings, inversion techniques
- GEOS-Chem supposed to be state-of-the-art but struggles to reproduce limited observations
  - OH & NO_x too low, isoprene + OVOCs too high
  - Model HCHO columns 10-100% too high!

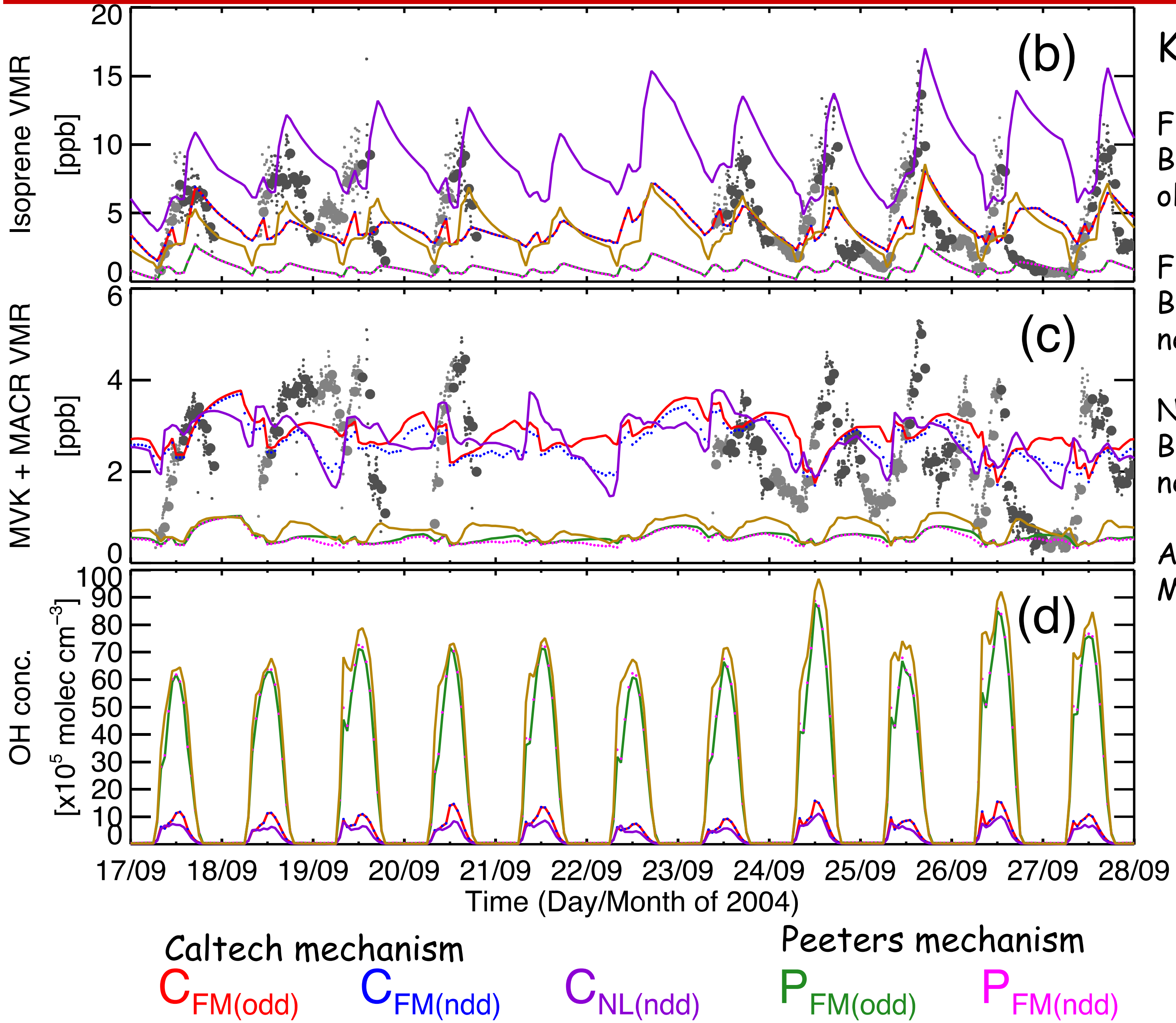
First time a CTM has been driven by both of these isoprene emissions inventories

Contrasting Isoprene Emissions Inventories

MEGAN (CANOPY-SCALE)	LPJ-GUESS (LEAF-SCALE)
• E = EF × Activity Factors • Use MODIS LAI for seasonal changes in vegetation	• $E = J \times \varepsilon \times \alpha \times f_i$ • Use LPJ-GUESS DVM for seasonal changes in vegetation

MEGAN-Hybrid	MEGAN-PCEEA	LPJ (GC)	LPJ (CRU)
5-layer canopy model	Parameterized model	GEOS-5 meteorology	CRU meteorology
Guenther et al. 1995,1999,2006	*Guenther et al. 2006*	*Arneth et al. 2007,2010*	*Arneth et al. 2007,2010*

Model performance @ TROFFEE (~60W,2S)



Key:

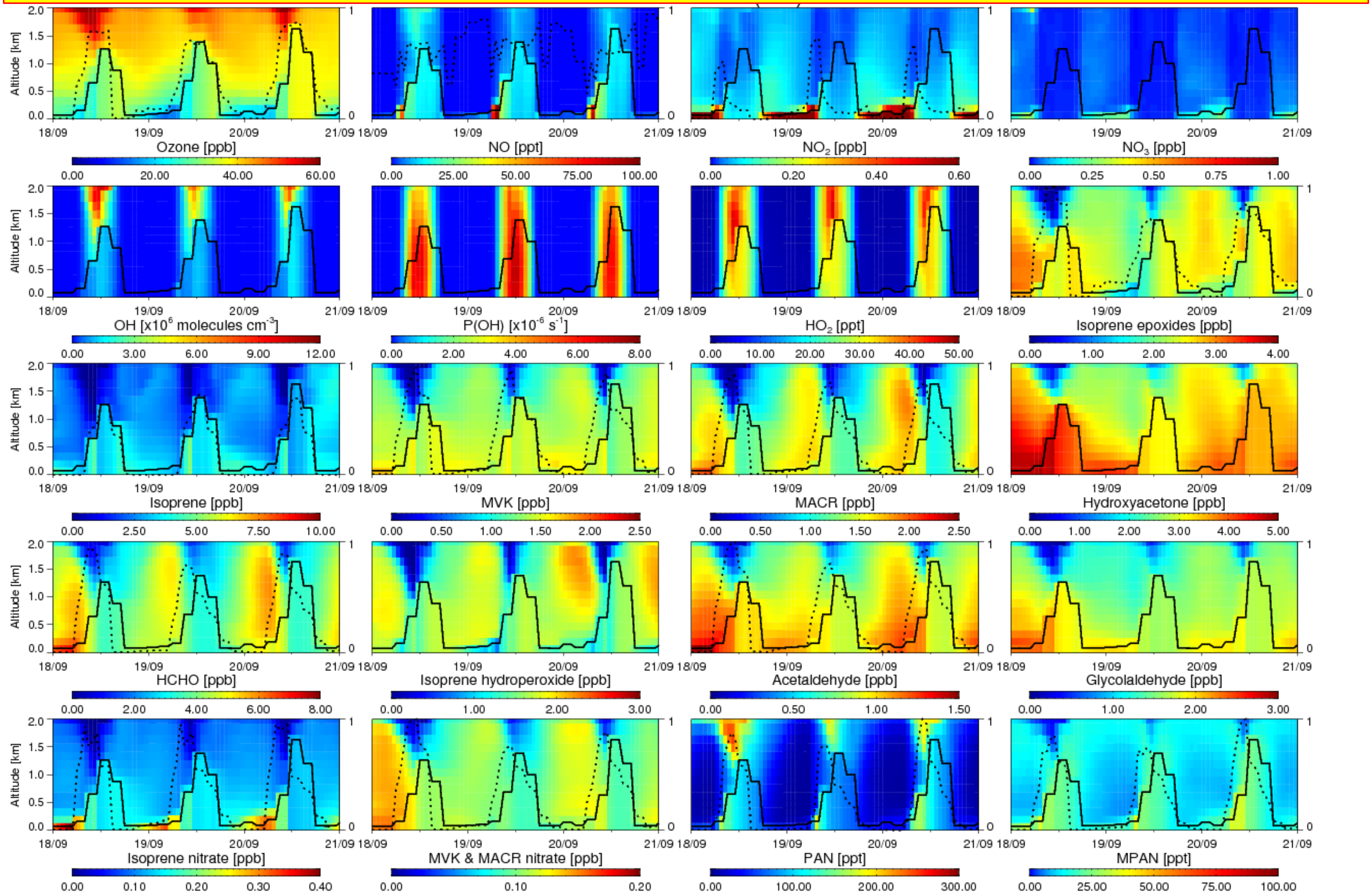
FM(odd) = BL full-mixing old dry deposition

FM(ndd) = BL full-mixing new dry deposition

NL(ndd) = BL non-local mixing new dry deposition

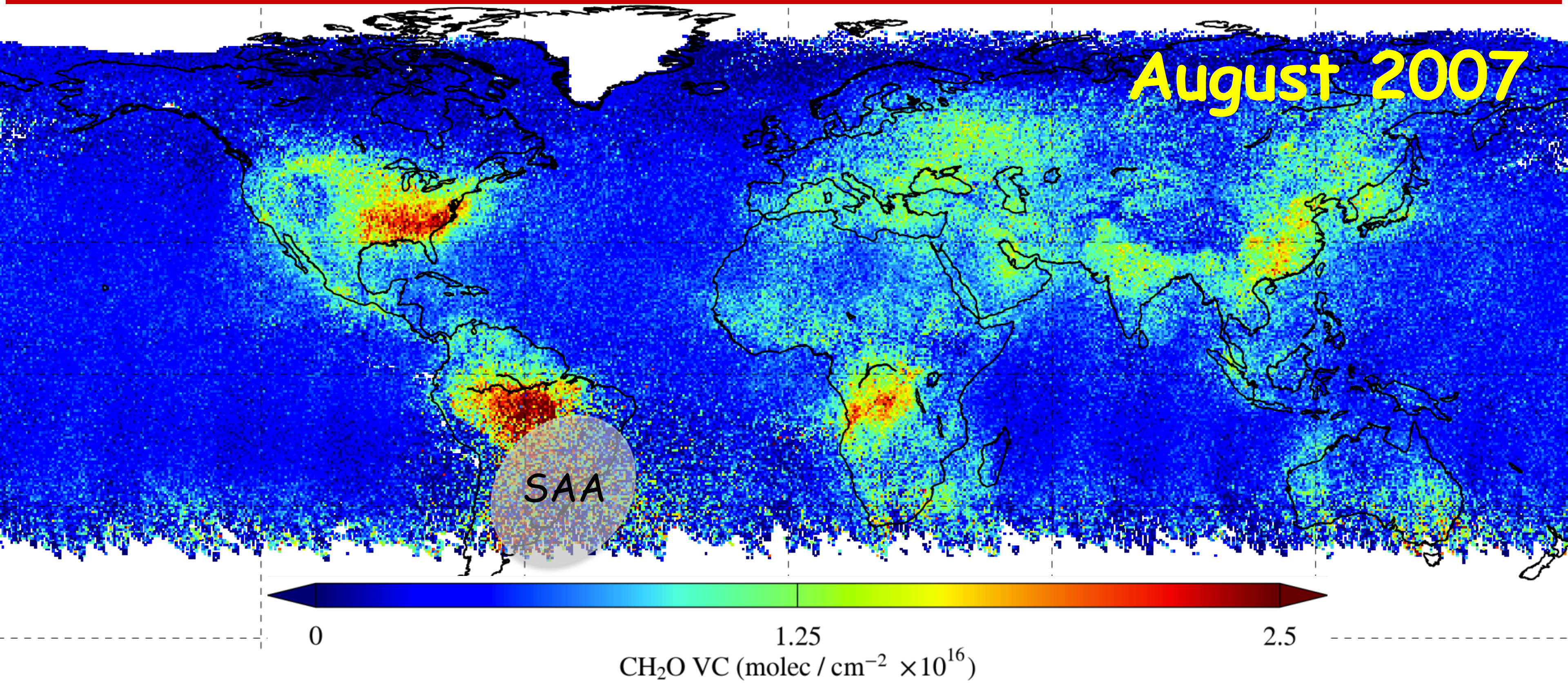
All scenarios here use MEGAN-PCEEA emissions

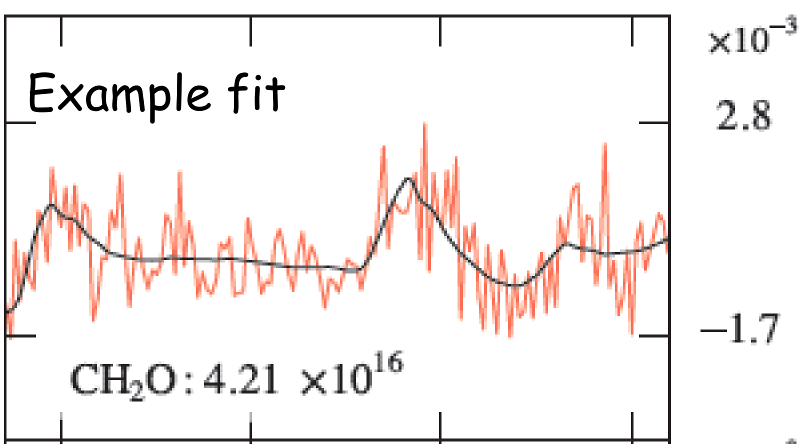
In situ observations are needed to understand diurnal photochemistry



Chemistry: Caltech **BVOC Emissions:** MEGAN PCEEA **Dry deposition:** Old ('slow') scheme **BL mixing:** full-mixing

GOME-2 HCHO retrievals at U. Leicester





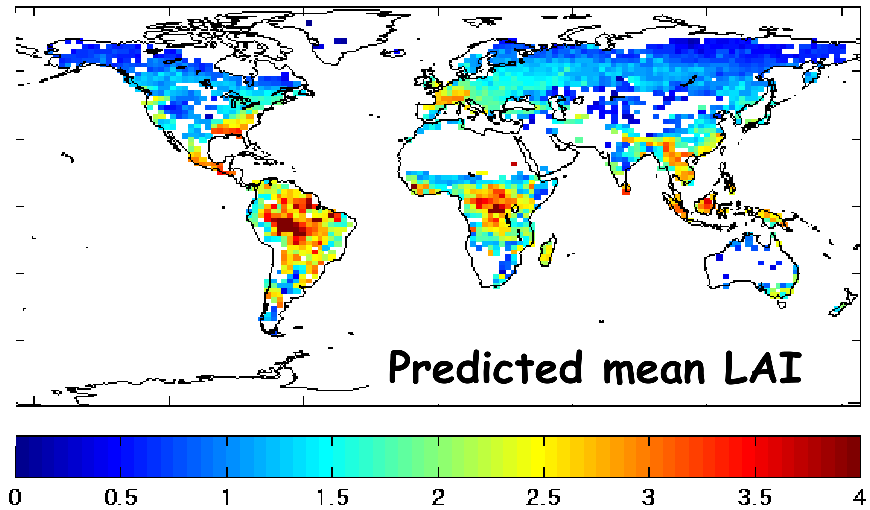
- To include a detailed examination of air-mass factors (= slant/vertical)
- Data will need validating
  - (MAX)-DOAS

Tropical leaf phenology inferred from MODIS LAI

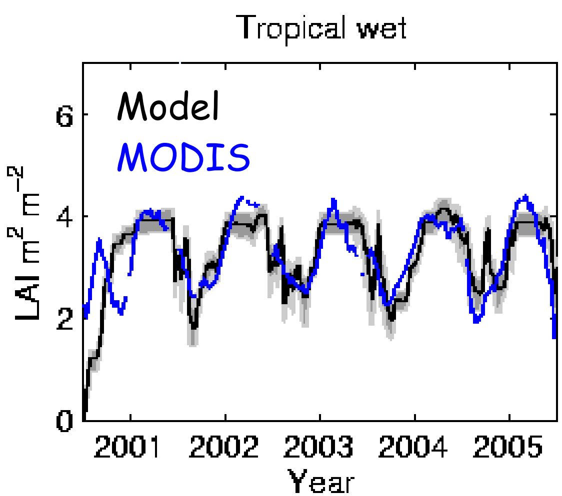
Process based model which predicts phenology as an optimal strategy for carbon gain.

Model fitted to 5 years of MODIS LAI data using a Bayesian algorithm

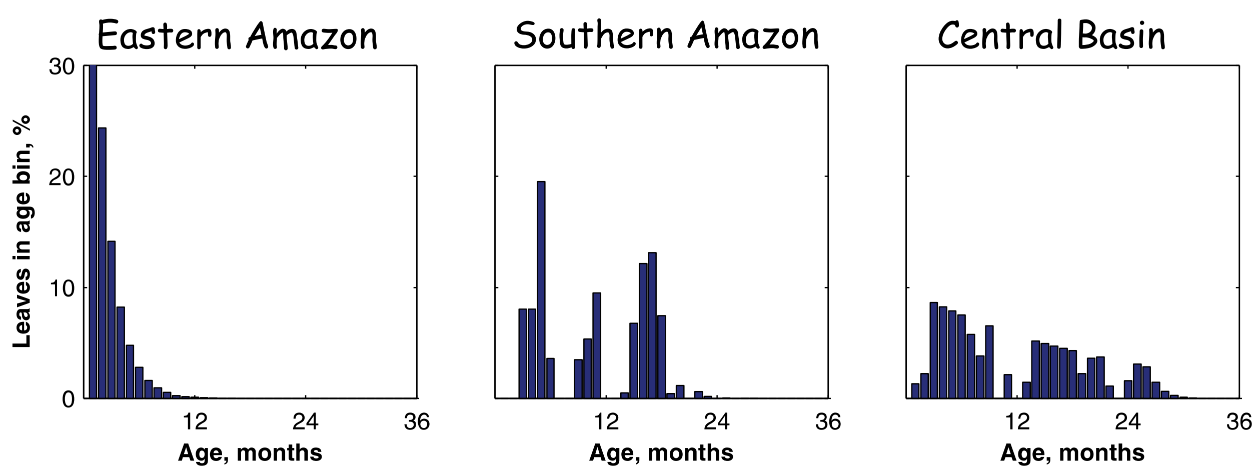
In wet tropical forests we predict an increase in LAI in response to light during the dry season



Model performance



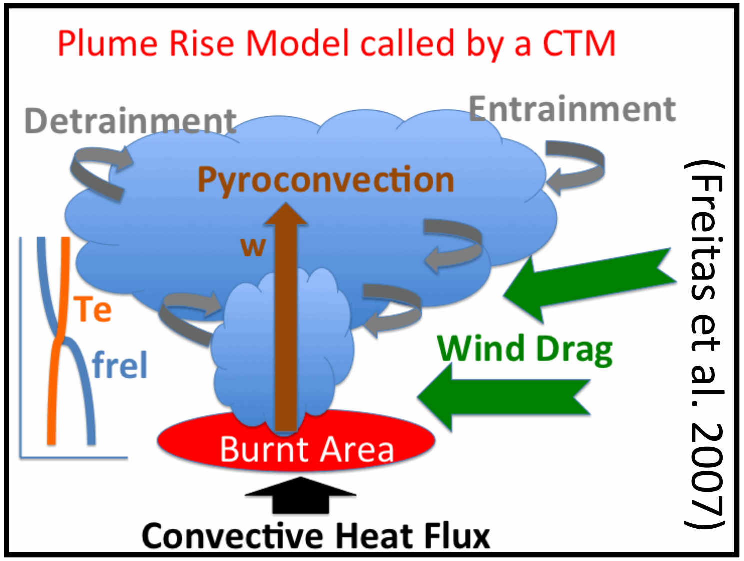
The model estimates the frequency distribution of leaf ages (months) over the Amazon basin.



Contact: Silvia Caldararu of U. Edinburgh

Caldararu et al, BGD, 2012

Estimating pyroconvection from fire radiative power



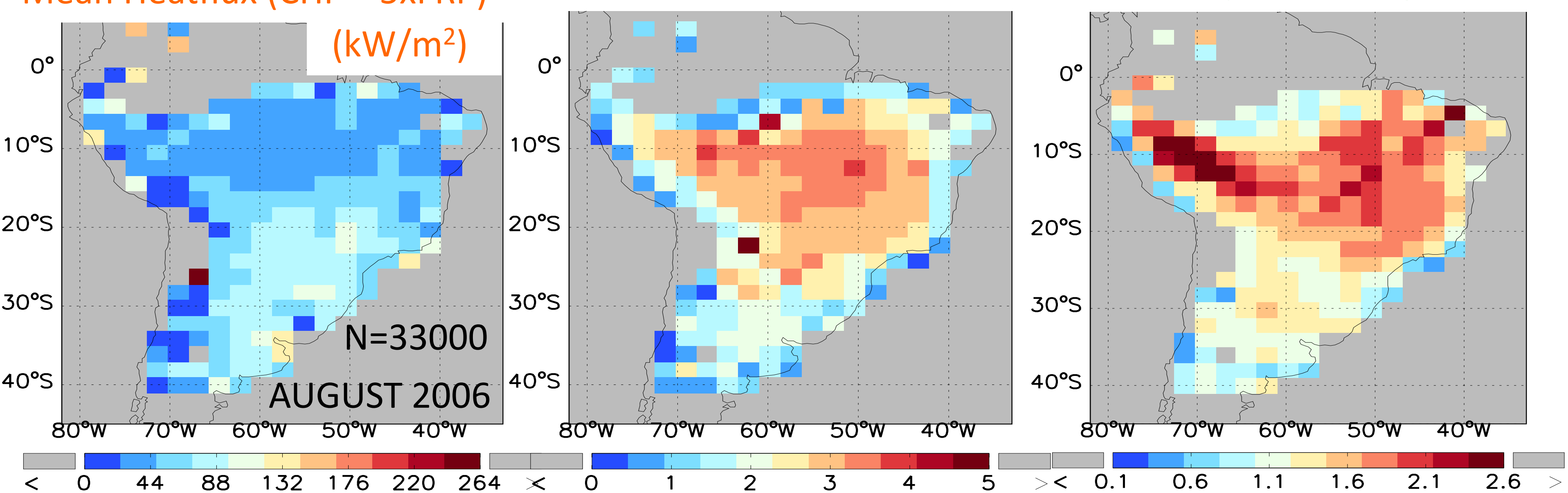
- ½ million global FRP and fire area observations in 2006 from MODIS (Wooster et al. 2005) .
- Over South America CHF is typically 1--80 kW/m^2 and fire size is <5 ha
- Pyroconvection injection heights are typically < 3 km.
- We now assess the impact of pyroconvection on biomass burning emission estimates inferred from MOPITT CO column measurements.

Contact: Sigfried Gonzi of U. Edinburgh

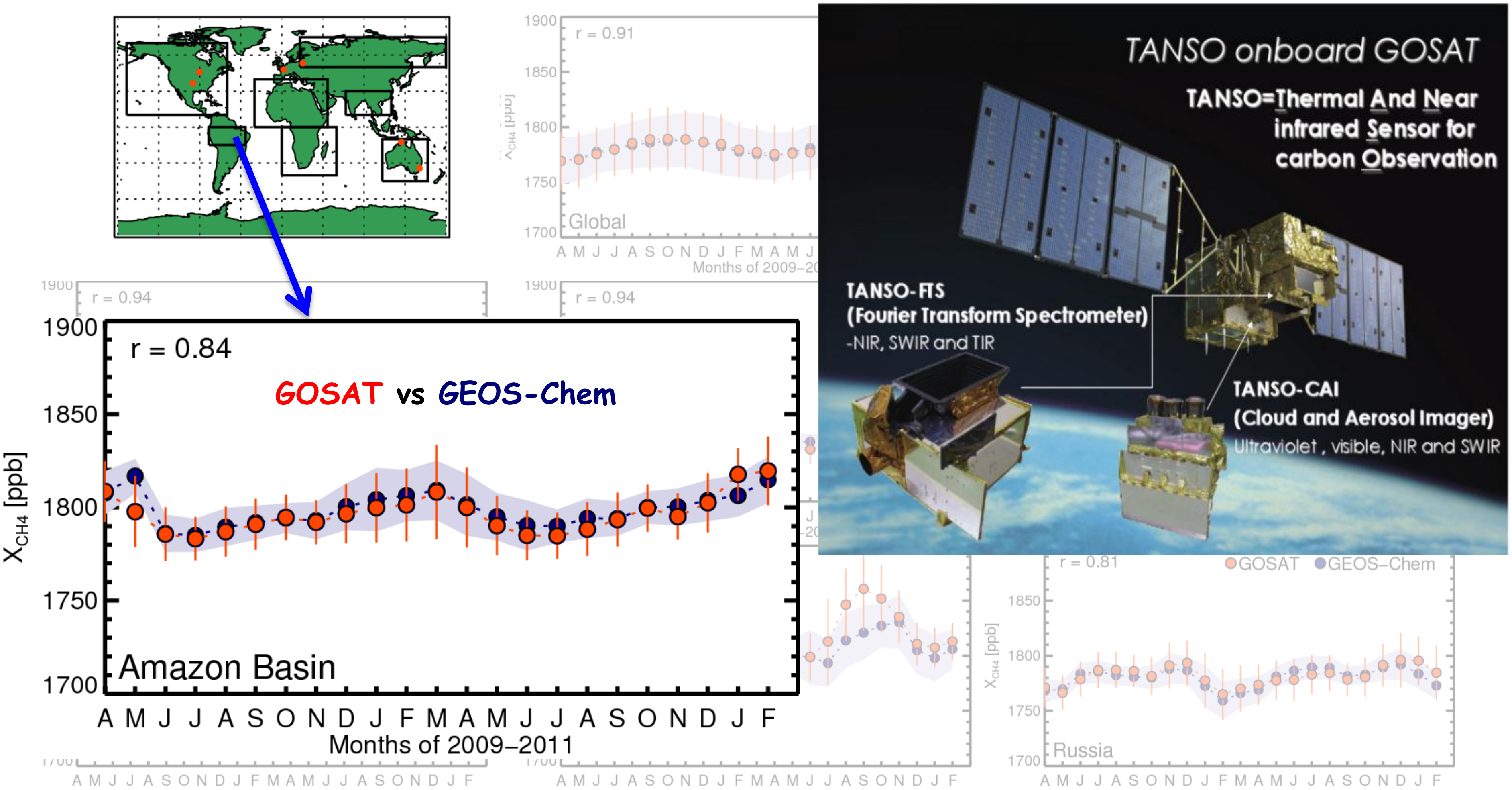
Mean Heatflux (CHF = 5xFRP)

Max. Injection Height (km)

Mean Injection Height (km)



Observing atmospheric CH_4 using GOSAT



Next generation: **Tropical Carbon Mission (TCM)**

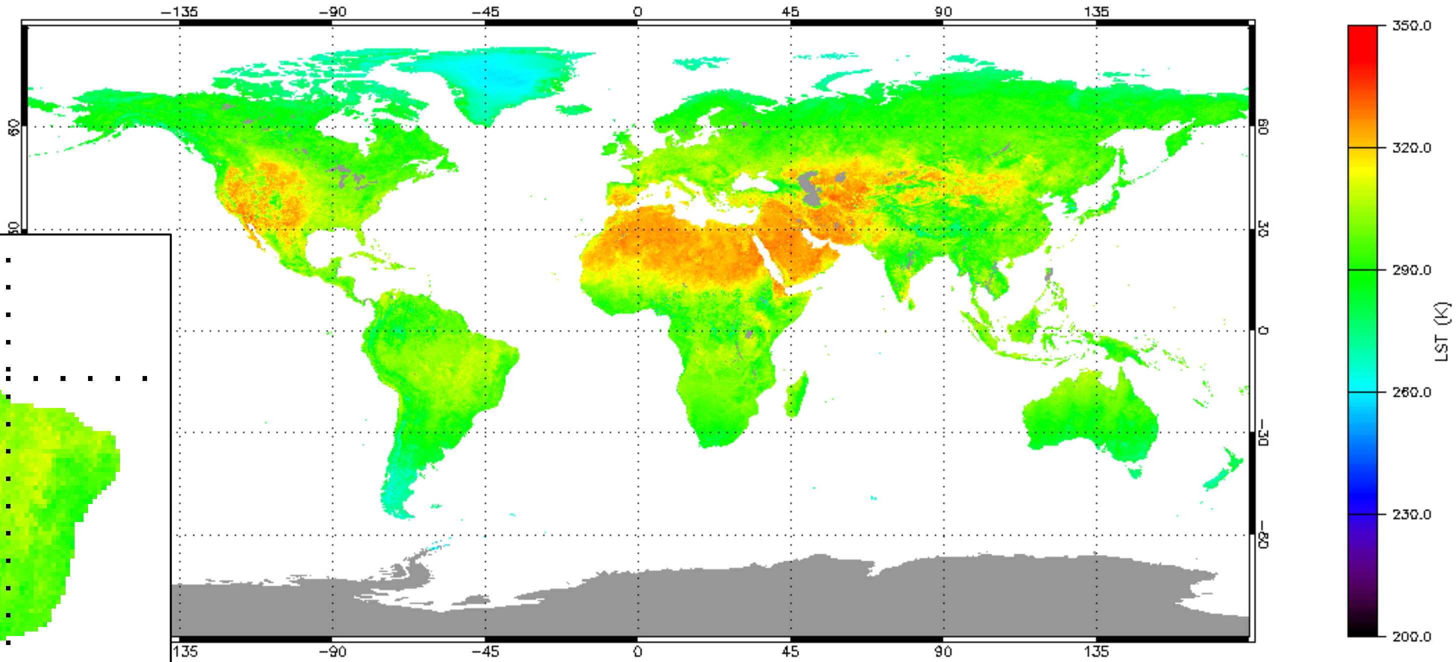
A proposed bilateral mission between the UK (Edinburgh, Leicester, SSTL) and JPL/NASA

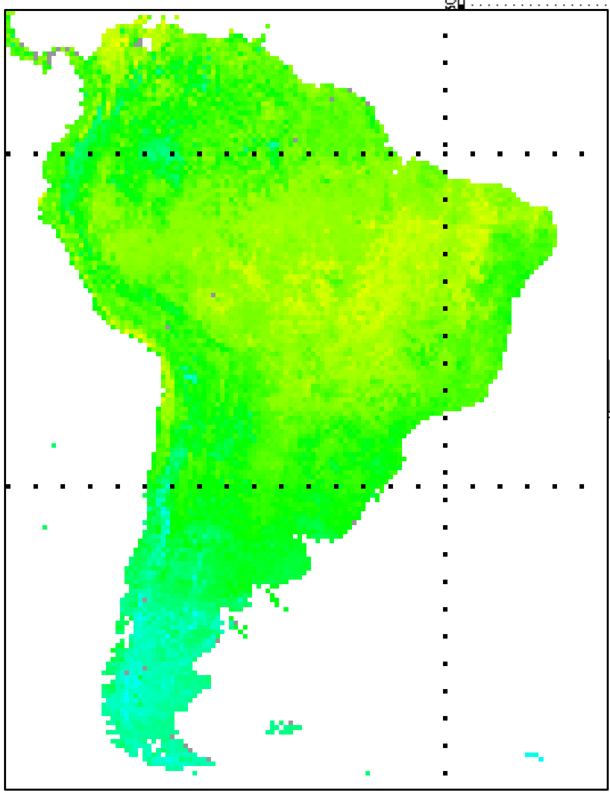
Primary objectives: Measure densely-sampled CO_2, CH_4 and CO columns over Tropics to improve understanding of tropical carbon cycle

Contact: Hartmut Boesch of U.Leciester

AATSR Land Surface Temperature (LST)

Level 3 data:
Daytime July 2006

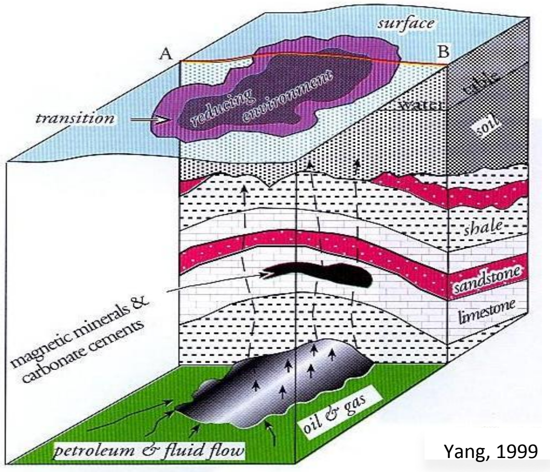




- Land surface temperature (LST) is the radiative skin temperature (~20μm) of the land
  - It determines the emission of surface-to-atmosphere long-wave radiation and exerts control over the partitioning of energy into latent and sensible heat fluxes, and heat flux into the ground
- Derived from Advanced Along Track Scanning Radiometer (ENVISAT) thermal IR measurements using an algorithm that corrects the atmospheric effects based on the differential absorption in adjacent channels
- LST can be used to drive/constrain land-surface models (e.g., UK Met Office's JULES model)

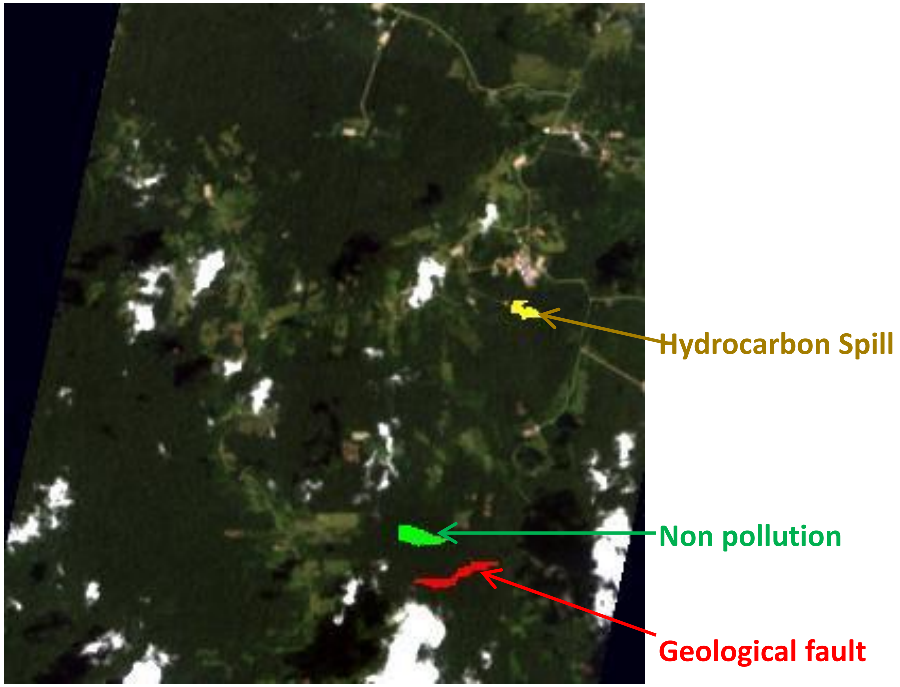
Contact:
John Remedios
of U.Leciester

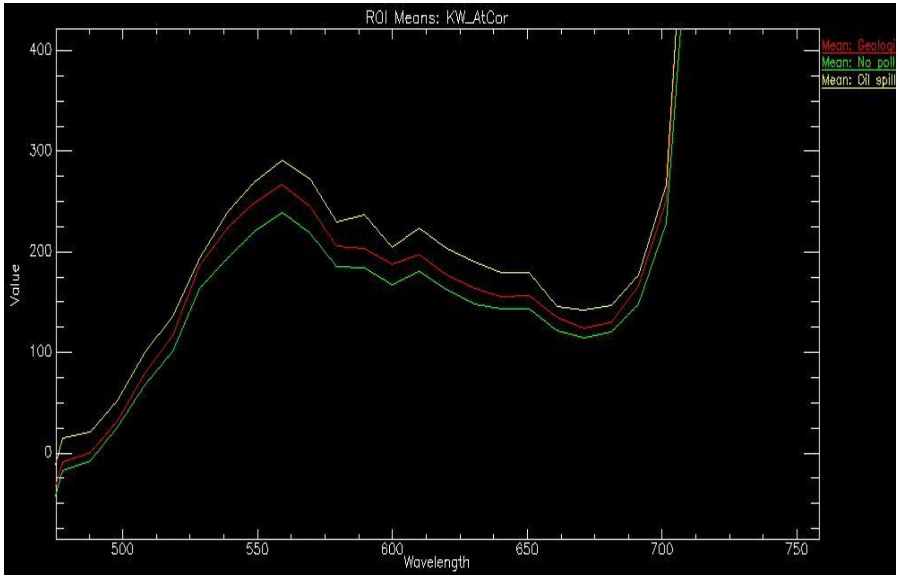
Detection of vegetation stress arising from hydrocarbon seepage in the Amazon rainforest



Yang, 1999

- Hydrocarbon seepage from geological reservoirs to the surface can cause vegetation stress – can this be detected from space?
- Preliminary results show a high reflectance response in areas influenced by hydrocarbons (spill and geological fault).
  - A reduction in the vegetation pigments (chlorophyll) is an indicator of vegetation stress correlates well with affected areas
- Field campaign to collect bio-physical/chemical parameters.
  - Scaling-up process to obtain reflectance at top-of-canopy using leaf/canopy RTMs.
- Use modelled reflectances to determine seepage areas from hyperspectral satellite images (Hyperion, EO-1)





Contact: Paul Arellano / Kevin Tansey of U. Leciester

Some things to think about…

- Surface emissions and tropospheric photochemistry in tropical environments are still very uncertain (despite all recent papers)
- Satellite observations put campaign data into a wider context
- Satellite observations allow examination of seasonal and inter-annual variability
- Satellite observations (usually) require models
  - In the retrievals themselves (a priori constraints)
  - To get to the science (e.g., top-down emissions)
- Not enough observations to validate satellite products
  - Especially NO_x, HCHO + other OVOCs
- Not enough observations to constrain models
  - Especially type, duration, vertical extent, diurnal cycle
- UK remote sensing groups welcome collaboration
  - Think broader than just measurements of gases/aerosols (e.g., LST)
  - How can UK data be used in ongoing/future Brazilian research?

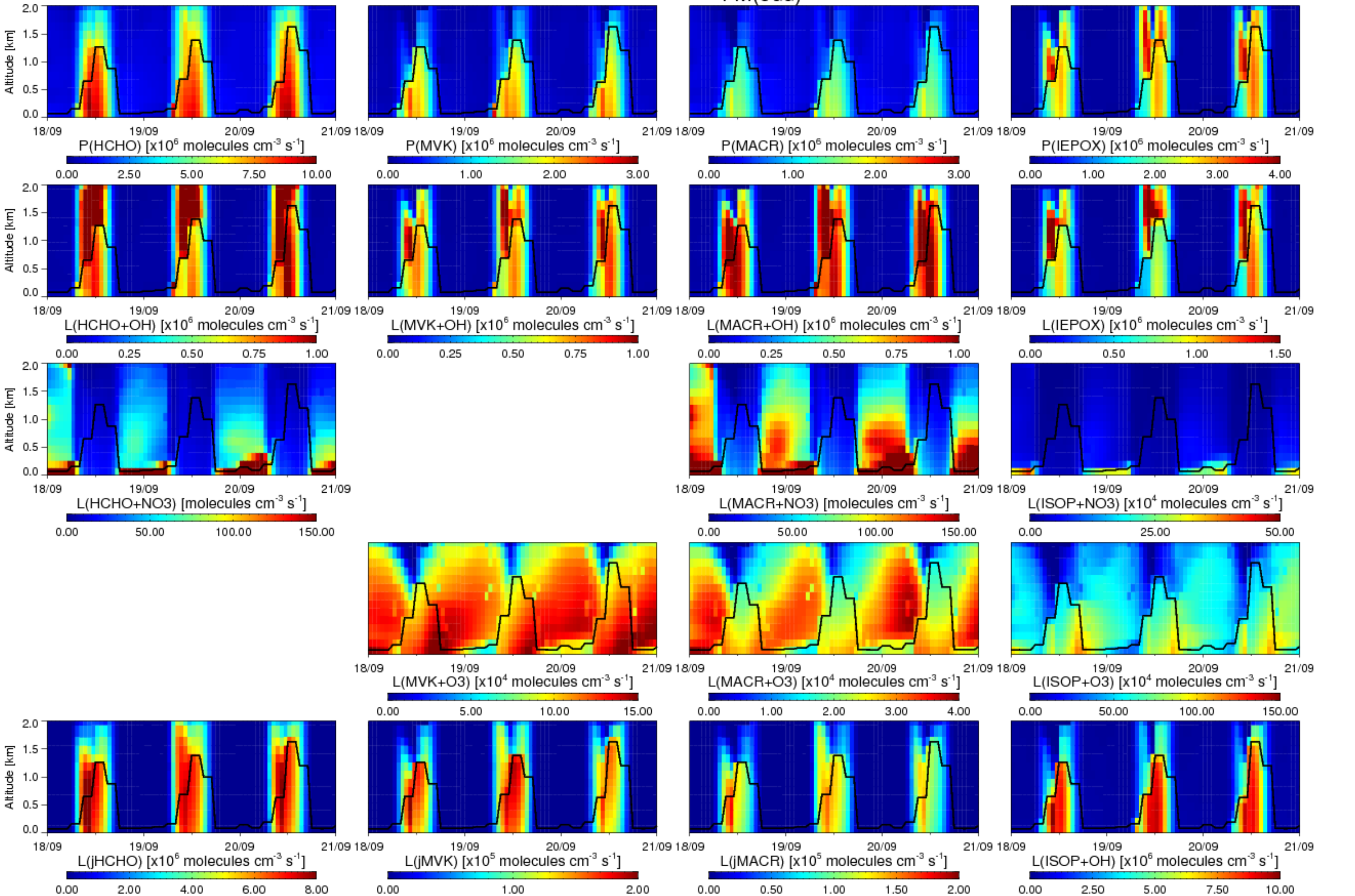
…and a (selfish) personal wish list

- Build firm links to Brazilian groups
  - Knowledge exchange
  - Data exchange (EO and model simulations)
  - Inclusion/collaborative research proposals
  - Access to Brazilian models (if required)
- Long term measurements sampling full diurnal cycle (but anything is a bonus)
  - Isoprene / monoterpene fluxes
  - Isoprene + OVOCs concentrations (in and above canopy, BL)
  - Concentrations of standard tracers (O_3, CO, NO_x, etc.)
  - OH/HO_2 would be great :0)
  - Soil NO_x emissions
  - Micro-meteorological conditions
  - LAI and leaf fall
- Establish DOAS instrument for satellite validation (permanent/temporary)

Thank you for listening.
Any questions?

Production and loss rates of key species

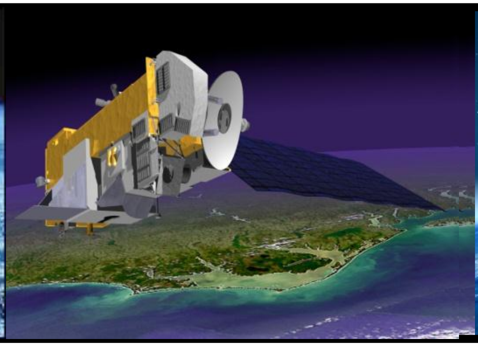
Scenario: $C_{FM(odd)}$



Chemistry: Caltech **BVOC Emissions:** MEGAN PCEEA **Dry deposition:** Old ('slow') scheme **BL mixing:** full-mixing

A wealth of HCHO column observations






GOME
1996-2004

SCIAMACHY
2004-2010

OMI
2005-present

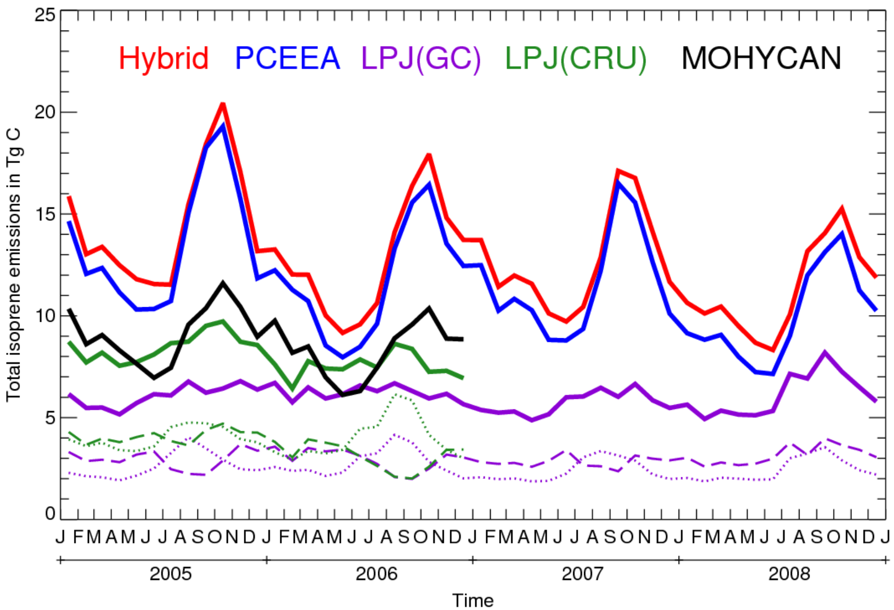
GOME-2
2007-present

1996 → **2011+**

Instrument	Platform	Spectral Resolution (nm)	Fitting window (nm)	Global coverage	Pixel size (km)	Swath (km)	Equator crossing time
GOME	ERS-2	0.17/0.29	337.35 -- 356.12[1]	3 days	40x320	960	10.30
SCIAMACHY	ENVISAT	0.26/0.44	328.50 --346.00[2]	6 days	30x60	960	10.00
OMI	AURA	0.42/0.63	327.50 --356.50[3]	daily	13x12; 13x128	2600	13:45
GOME-2	MetOp-A	0.28/0.54	328.50 --346.00[2]	~daily	40x80	960	09:30

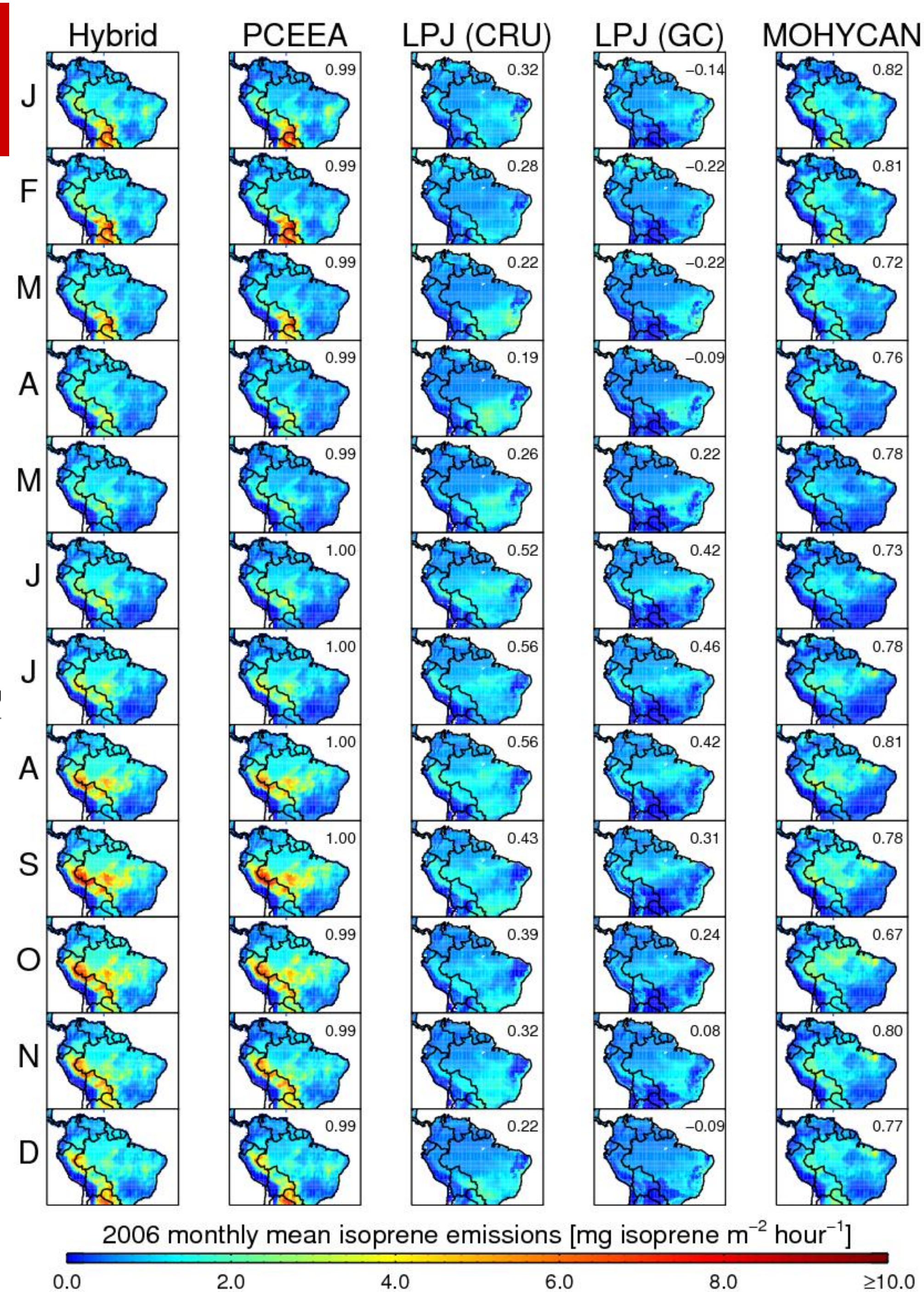
[1] Chance et al 2008 [2] De Smedt et al 2008 [3] OMI ATBD (T. Kuroso)

Why we need top-down emissions estimates!

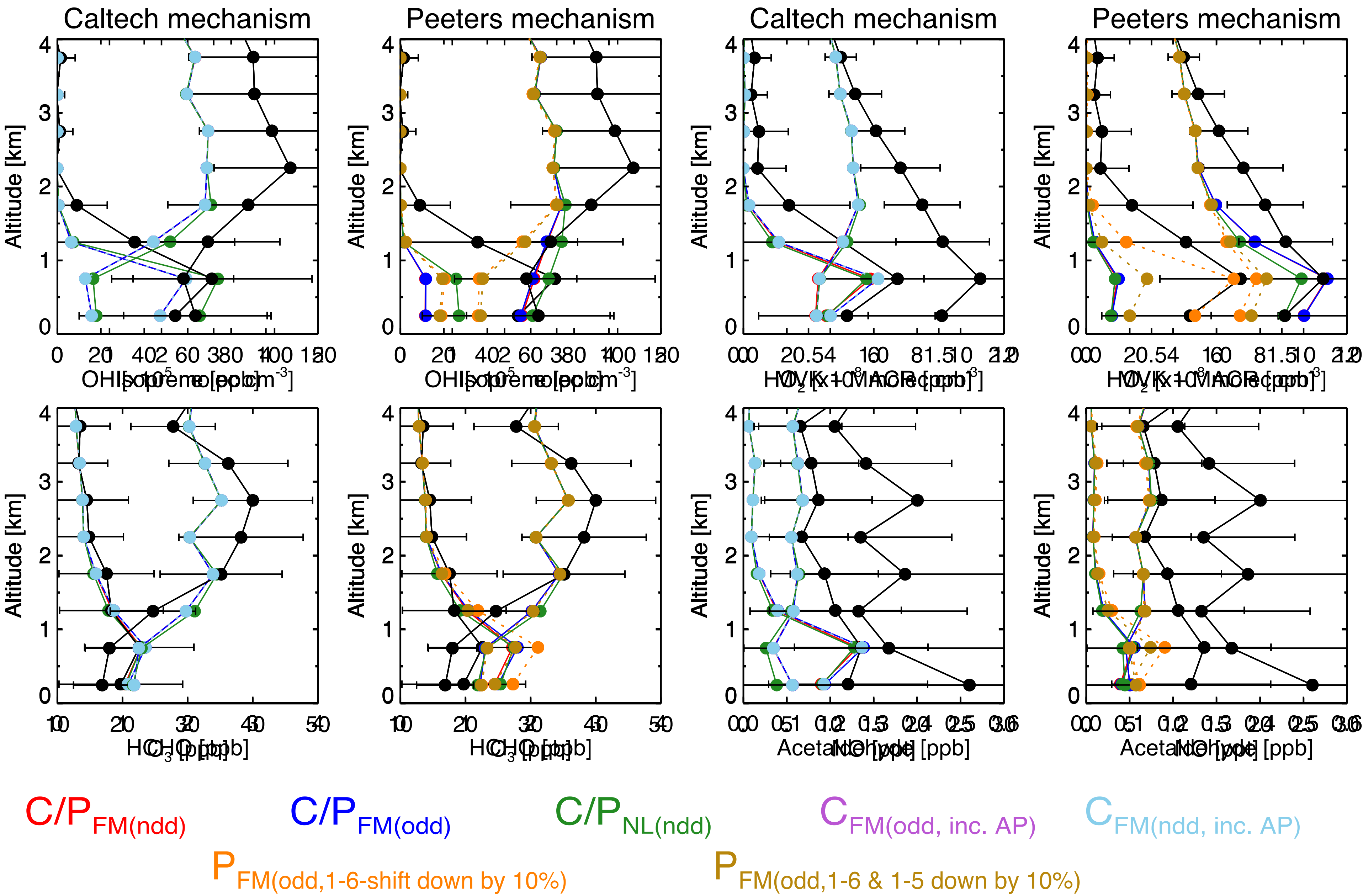


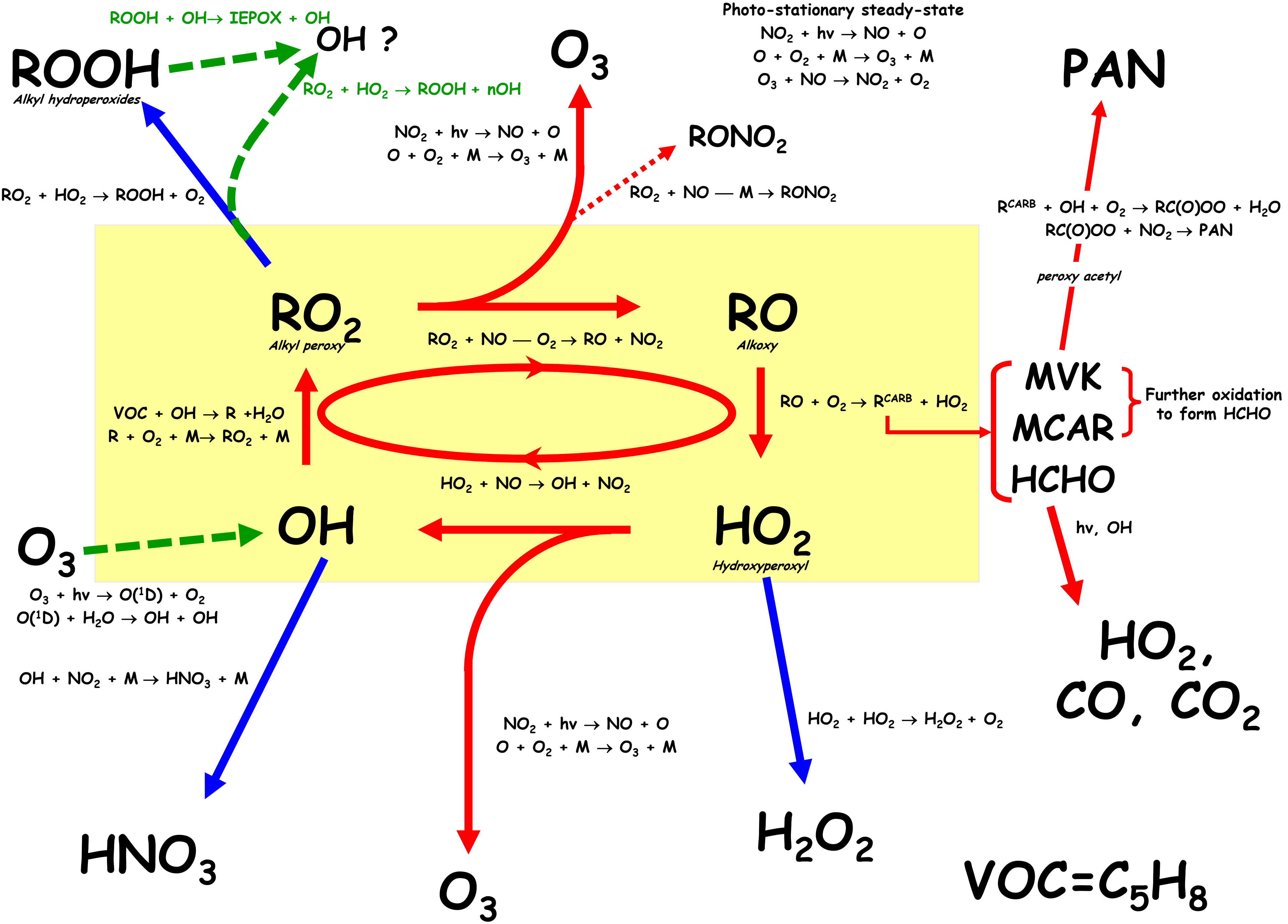
Model	2005	2006	2007	2008
Hybrid	174	154	152	135
PCEEA	162	140	138	119
LPJ (GC)	73	75	69	73
LPJ (CRU)	102	90	-	-
MOHYCAN	102	100	-	-

Units = Tg C



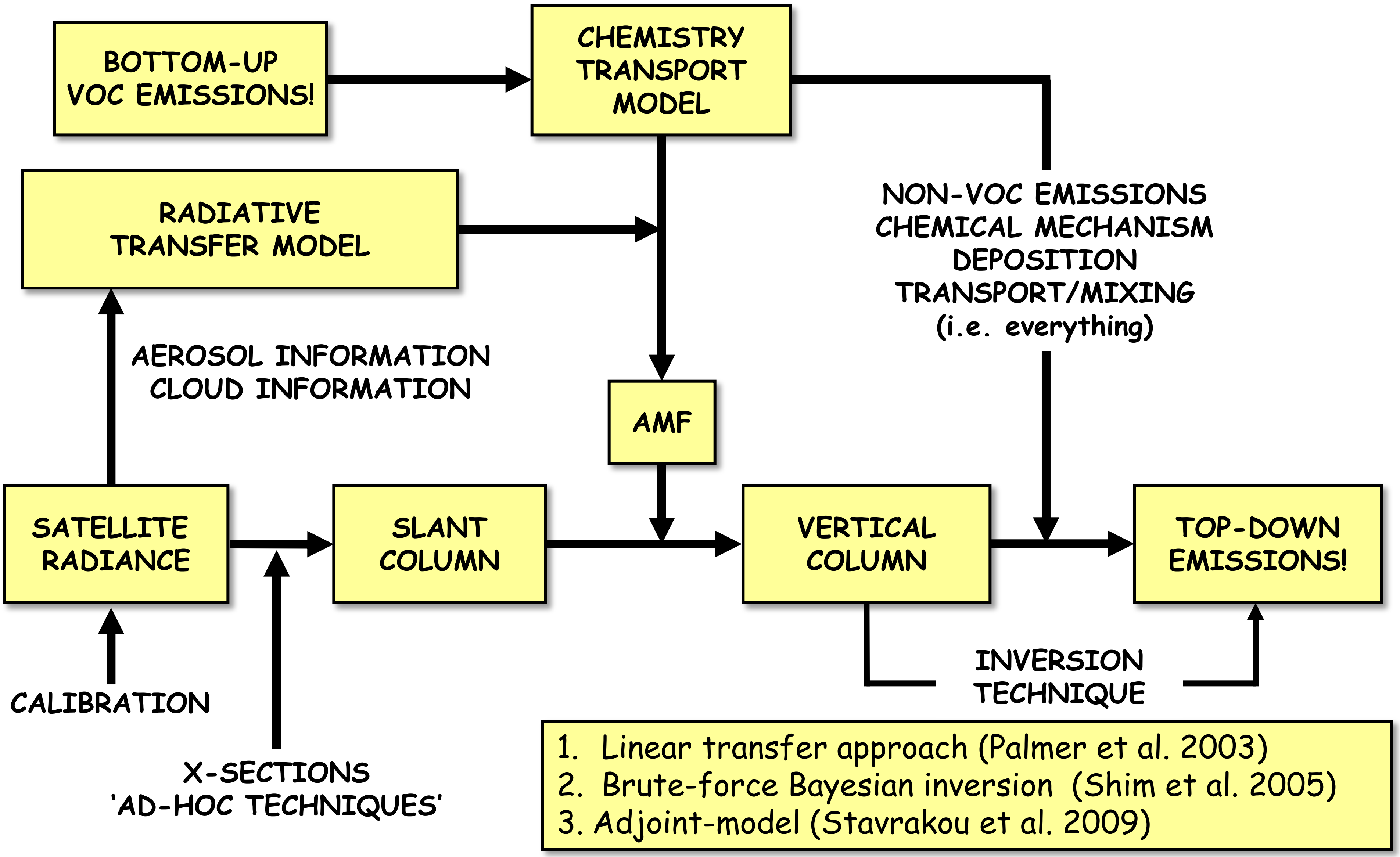
GABRIEL: Caltech vs. Peeters



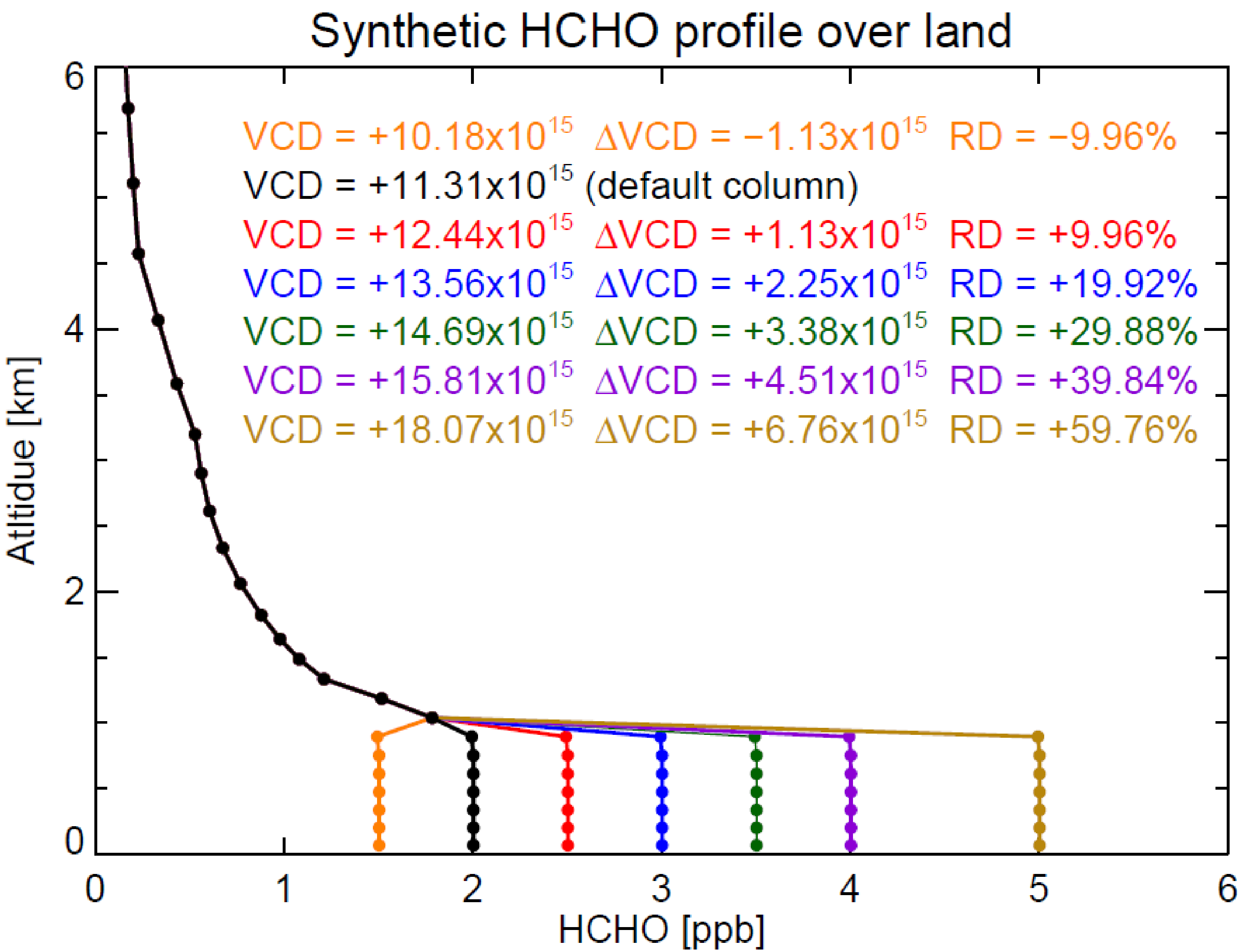


ROOH + OH→ IEPOX + OH
OH ?
ROOH
Alkyl hydroperoxides
RO2 + HO2 → ROOH + nOH
RO2 + HO2 → ROOH + O2
O3
NO2 + hv → NO + O
O + O2 + M → O3 + M
Photo-stationary steady-state
NO2 + hv → NO + O
O + O2 + M → O3 + M
O3 + NO → NO2 + O2
RONO2
RO2 + NO — M → RONO2
PAN
RCARB + OH + O2 → RC(O)OO + H2O
RC(O)OO + NO2 → PAN
peroxy acetyl
RO2
Alkyl peroxy
RO2 + NO — O2 → RO + NO2
RO
Alkoxy
RO + O2 → RCARB + HO2
MVK
MCAR
HCHO
Further oxidation
to form HCHO
VOC + OH → R +H2O
R + O2 + M→ RO2 + M
HO2 + NO → OH + NO2
O3
OH
HO2
Hydroxyperoxyl
hv, OH
O3 + hv → O(1D) + O2
O(1D) + H2O → OH + OH
OH + NO2 + M → HNO3 + M
NO2 + hv → NO + O
O + O2 + M → O3 + M
HO2 + HO2 → H2O2 + O2
HO2,
CO, CO2
HNO3
O3
H2O2
VOC=C5H8

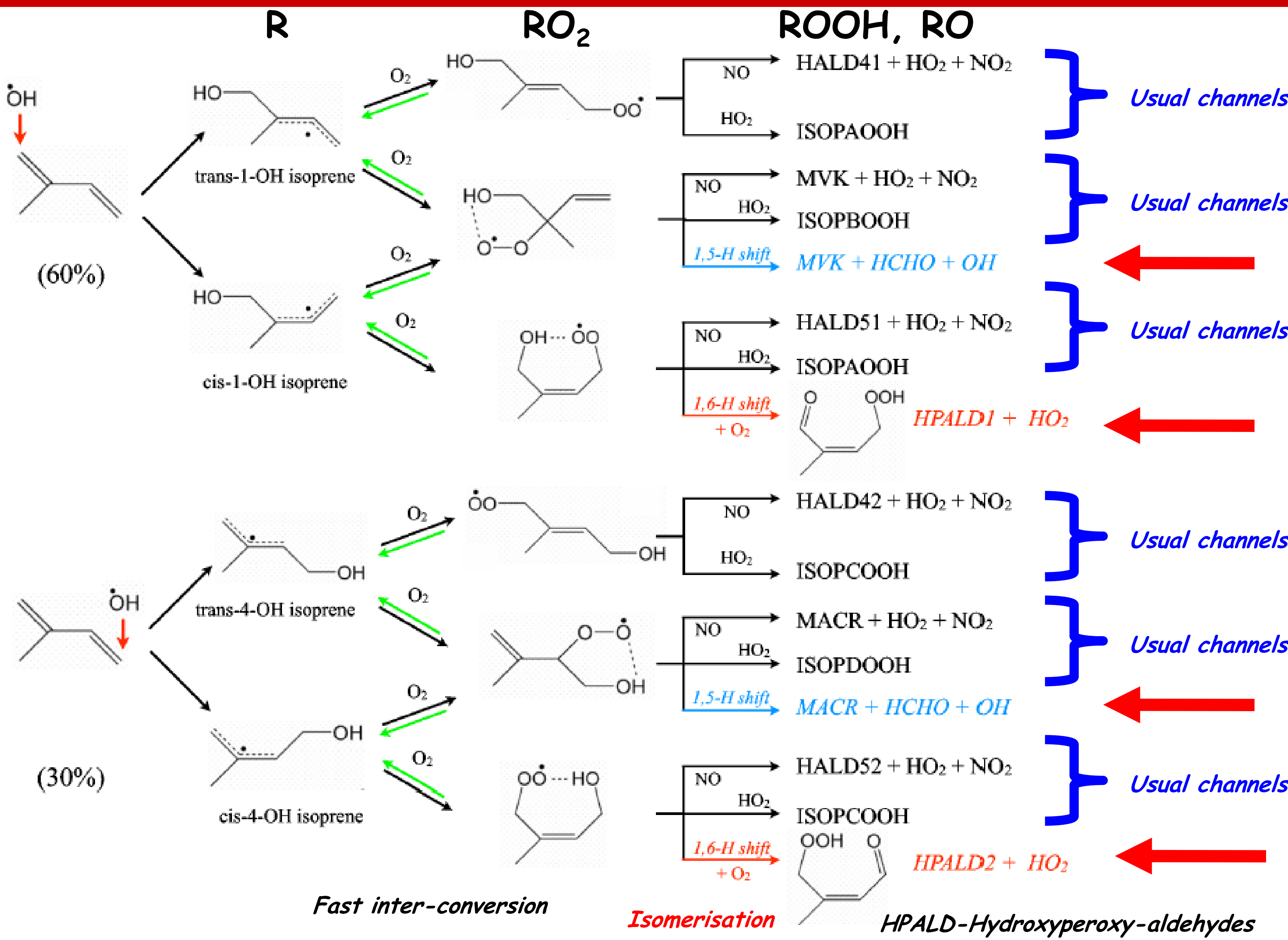
A standard approach for inferring emissions



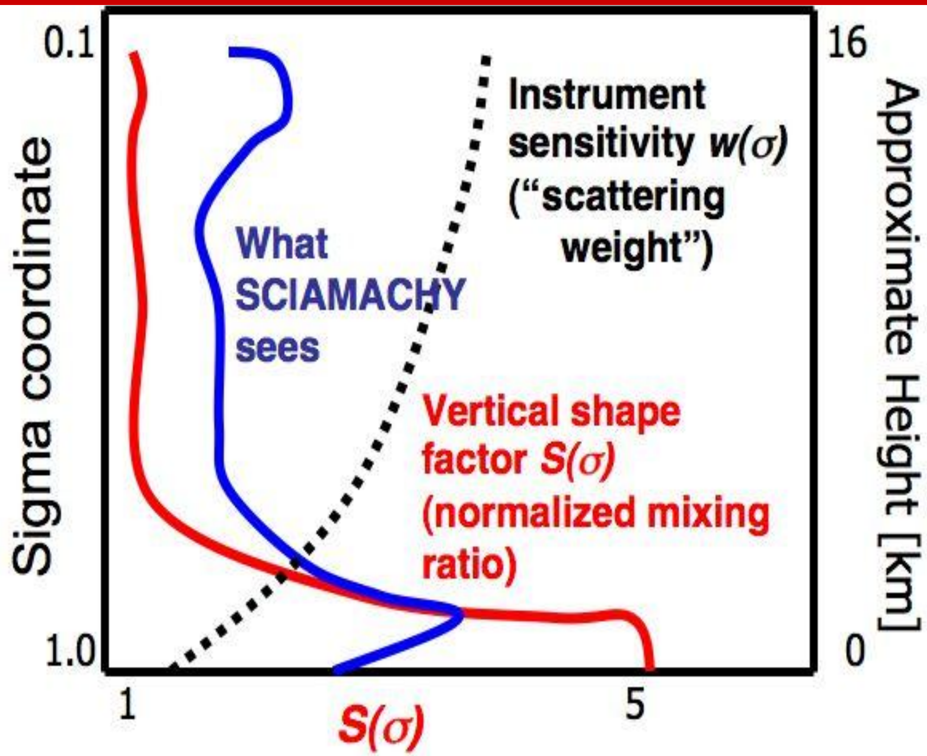
Is this a disaster?



LIMO Scheme


R
RO2
ROOH, RO
OH
(60%)
trans-1-OH isoprene
cis-1-OH isoprene
O2
NO
HO2
HALD41 + HO2 + NO2
ISOPAOOH
Usual channels
MVK + HO2 + NO2
ISOPBOOH
1,5-H shift
MVK + HCHO + OH
HALD51 + HO2 + NO2
ISOPAOOH
1,6-H shift
+ O2
HPALD1 + HO2
(30%)
trans-4-OH isoprene
cis-4-OH isoprene
HALD42 + HO2 + NO2
ISOPCOOH
MACR + HO2 + NO2
ISOPDOOH
MACR + HCHO + OH
HALD52 + HO2 + NO2
ISOPCOOH
HPALD2 + HO2
Fast inter-conversion
Isomerisation
HPALD-Hydroxyperoxy-aldehydes

Air mass factor (AMF) calculation



$$AMF = \frac{SCD}{VCD} = \frac{AMF_G}{P_{Surf}} \int_{P_{Surf}}^{0} \omega(p) S(p) dp$$

ω(p) describes the sensitivity of backscattered spectrum to species at pressure *p*	*S(p)* normalized vertical distribution (shape factor) of species

- Atmospheric scattering critical for interpretation of solar backscatter UV-VIS spectra
  - AMF is sensitive to the vertical distribution of (optically thin) species
- Calculation requires:
  - HCHO profile (error ~10%)
  - UV albedo (error ~10%)
  - Aerosol AODs (error 10-40%)
  - Cloud information (error 20-30%)
- AMF for each scene computed as weighted sum of AMFs for clear and cloudy fractions (using reflectivity)

$$AMF = \frac{AMF_a R_a (1 - f) + AMF_c R_c f}{R_a (1 - f) + R_c f}$$