KALMAN FILTER: A REVIEW

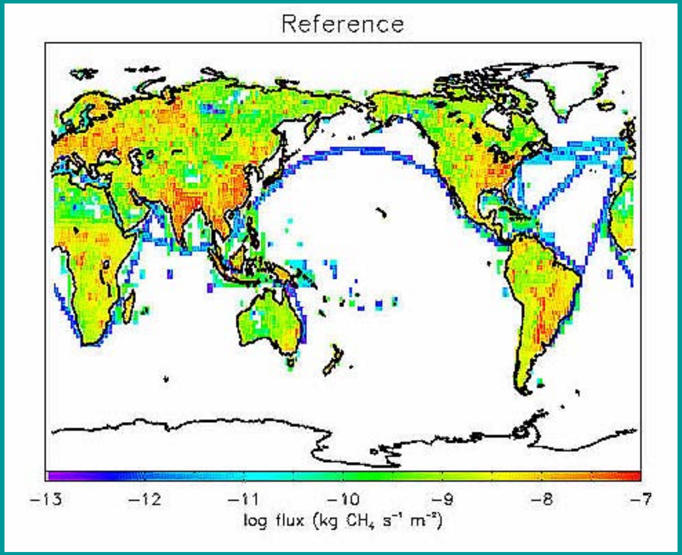
Table 1: Kalman Filter Equations*

Definition	Equation
Measurement equation (model)	$y_k^o = H_k x_k^t + \varepsilon_k$; $y_k = H_k x_k^f$
System (state) equation (model)	$x_k = M_{k-1} x_{k-1} + \eta_{k-1}$
State update	$x_k^a - x_k^f = K_k (y_k^o - y_k)$
Error Update	$P_k^a = (1 - K_k H_k) P_k^f$
Kalman gain update	$K_k = P_k^f H_k^T (H_k P_k^f H_k^T + R_k)^{-1}$
State time extrapolation	$x_k^f = M_{k-1} x_{k-1}^a$
Error time extrapolation	$P_k^f = M_{k-1} P_{k-1}^a M_{k-1}^T + Q_{k-1}$
System random forcing covariance	$Q_k = E(\eta_k \eta_k^T)$
Measurement error covariance	$R_k = E(\varepsilon_k {\varepsilon_k}^T)$
Estimation error covariance	$P_k = E(\nu_k {\nu_k}^T)$
Input measurement matrix	$= H_k = \partial y_k / \partial x_k$
Input system random forcing covariance	$= Q_k$
Input state extrapolation	$= M_k$
Input measurement	y_k^o
Input measurement error covariance	$= R_k$
Filter iteration	$- - - \to (k-1)^f, \to$ estimate $\to (k-1)^a, \to$ extrapolate $\to (k)^f, \to - - -$

*A superscript a or superscript f denotes respectively the value before (f) or after (a) an update of an estimate using measurements, and k denotes the measurement number. In general, errors are assumed random with zero mean and measurement and estimation errors are uncorrelated.

REVIEW OF THE CH4 INVERSE PROBLEM

Emissions from seven seasonally varying (3 wetland, 3 burning, rice) & two steady sources (animals & waste, coal & gas) to be optimally estimated as amendments to the (a priori) reference



Rest of the images removed due to copyright considerations.

See Figure 2. Chen, Y.-H. and R.G. Prinn, Estimation of atmospheric methane emissions between 1996-2001 using a 3D global chemical transport model, Journal of Geophysical Research, 111, D10307, doi:10.1029/2005JD006058, 2006.

5-YEAR AVERAGE SEASONAL CYCLES AND ERRORS (SELECTED AND ALL DATA SETS)

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See Figure 7. Chen, Y.-H. and R.G. Prinn, Estimation of atmospheric methane emissions between 1996-2001 using a 3D global chemical transport model, Journal of Geophysical Research, 111, D10307, doi:10.1029/2005JD006058, 2006.

CAPTURES EXPECTED SEASONAL CYCLES (RICE PEAKS EARLIER)

SIGNIFICANT YEAR-TO-YEAR EMISSION VARIATIONS

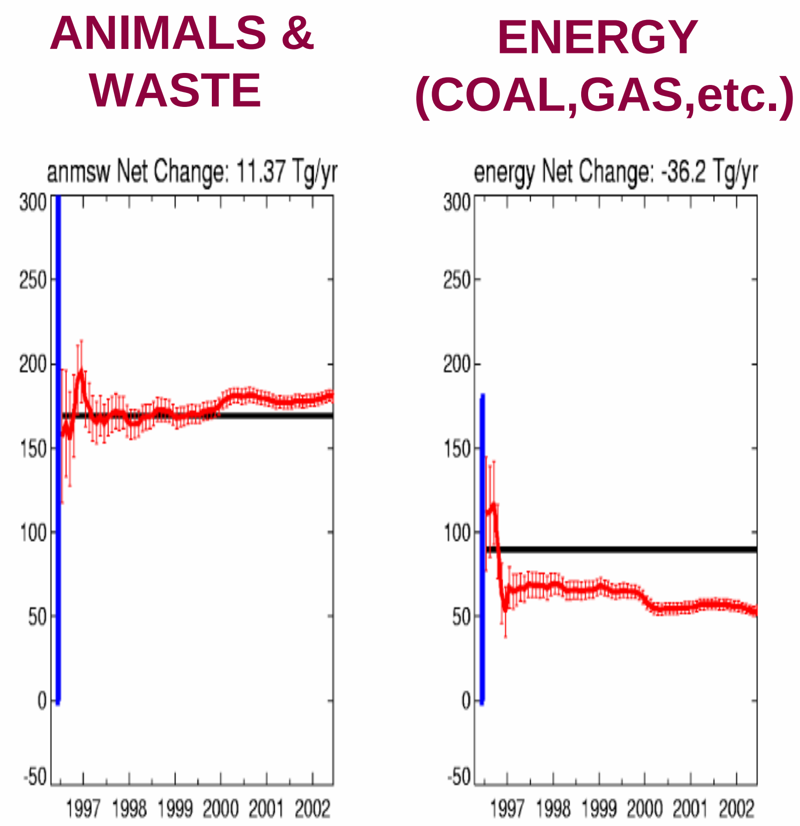
MONTHLY ANOMALIES (from 5-year mean annual cycles) using data from: (a) high frequency in situ sites and flask sites (blue lines), and (b) high frequency sites only (red lines)

***Note different vertical scale for each process**

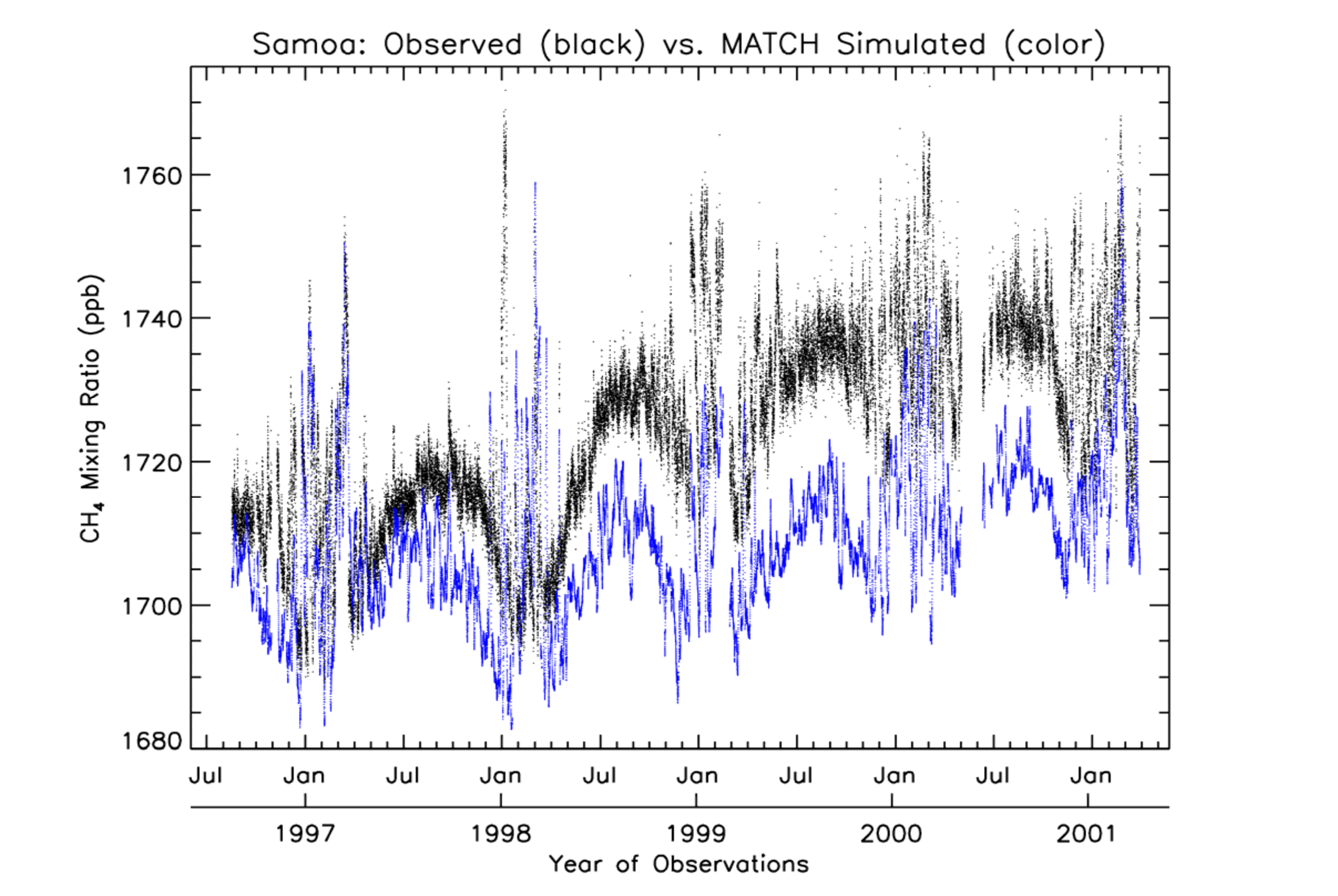
Images removed due to copyright considerations.

See the 8 sub-figures on the left in Figure 9. Chen, Y.-H. and R.G. Prinn, Estimation of atmospheric methane emissions between 1996-2001 using a 3D global chemical transport model, Journal of Geophysical Research, 111, D10307, doi:10.1029/2005JD006058, 2006.

Estimation of the steady fluxes and errors



Samoa observations versus model before inversion



Samoa observations versus model after inversion

Model with optimized emissions simulates observations at almost all sites but Samoa is odd in 1997-1999

WAS THERE A (tropics-weighted) OH DECREASE IN 1997-1999??

See Figure 12. Chen, Y.-H. and R.G. Prinn, Estimation of atmospheric methane emissions between 1996-2001 using a 3D global chemical transport model, Journal of Geophysical Research, 111, D10307, doi:10.1029/2005JD006058, 2006.

Global weighted average OH inferred from AGAGE CH_3CCl_3

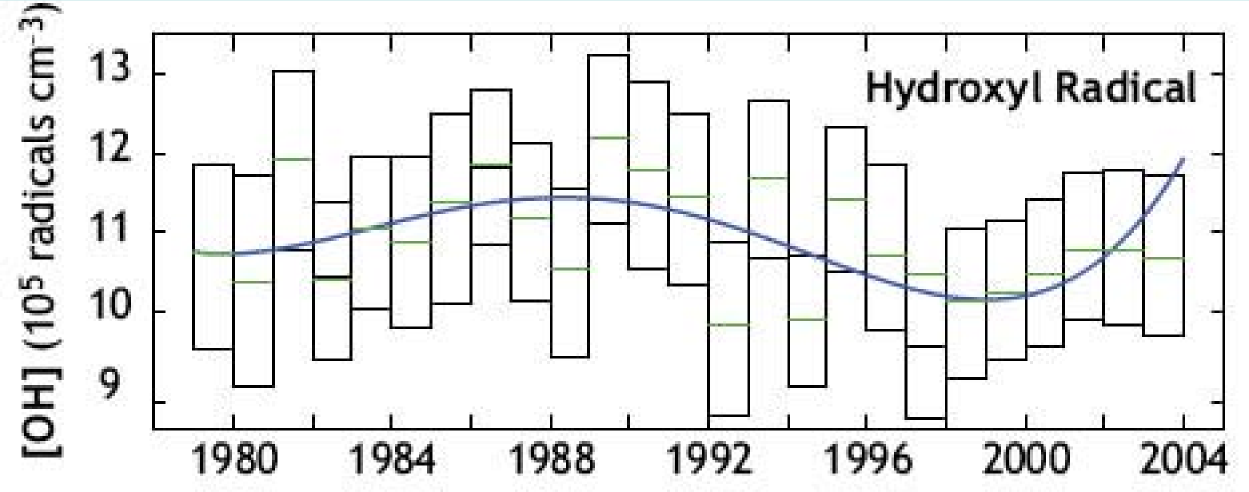


Image courtesy of AGAGE.

The inferred circa-1998 OH minimum coincides with massive global wildfires and a strong El Nino.

Summary: Interannual variability (Monthly Anomalies)

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See the 8 sub-figures on the right in Figure 9. Chen, Y.-H. and R.G. Prinn, Estimation of atmospheric methane emissions between 1996-2001 using a 3D global chemical transport model, Journal of Geophysical Research, 111, D10307, doi:10.1029/2005JD006058, 2006.

32-33 Tg yr^{-1} Total Emission increase in 1998 with 8-17 Tg yr-1 due to Rice regions !

Northern/Tropical Wetland and Rice Region Emissions dominate the total variability!

1998 wetland Flux Anomalies

Fluxes in Tg yr^{-1}	Northern Wetlands	Tropical Wetlands
Inversion	5-10	8.3-9.9
Bottom-up*	12	13

*wetland model driven by 1998 record temperature and large precipitation anomalies (Dlugokencky et al. (2001))

BUT Boreal Fires in Siberia may have also contributed to our deduced strong Northern wetlands increase!

Summary: 5-year averages

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See Figure 8. Chen, Y.-H. and R.G. Prinn, Estimation of atmospheric methane emissions between 1996-2001 using a 3D global chemical transport model, Journal of Geophysical Research, 111, D10307, doi:10.1029/2005JD006058, 2006.

COMPARED TO PREVIOUS ESTIMATES:

(1) ENERGY RELATED EMISSIONS SMALLER (RUSSIAN GAS LEAKS?)

(2) RICE RELATED EMISSIONS LARGER (PROXIMAL WETLANDS OR TROPICAL ECOSYSTEMS?)