Poster 98: Chemoautotrophic Production in Continental Shelf Waters Off The West Antarctic Peninsula

James T. Hollibaugh[1*], Brian Popp[2], Natalie Wallsgrove[2] and Tamara Allen[2]

1) Department of Marine Sciences, University of Georgia, Athens, GA, USA

2) Department of Earth Sciences, University of Hawai'i at Manoa, Honolulu, HI, USA

*) ORCID: 0000-0001-8037-160X; email address: aquadoc@uga.edu

ABSTRACT

We performed assays of chemoautotrophic carbon fixation and compared measured rates to rates predicted from oxidation of ammonia (AO), urea (UO) and nitrite (NO) N. Water samples used in this study were taken from aerobic shelf waters at stations on the continental shelf and slope west of the Antarctic Peninsula during January and February of 2018 (LMG1801). Chemoautotrophic carbon fixation rates averaged 1.8 and 1.7 nmol C L^{-1} d^{-1} in Winter Water (WW, 35-100 m) and Circumpolar Deep Water (CDW, 175-1000 m) water masses, respectively. Integrated over 1 year and a 440 m water column (excluding the Antarctic Surface Water mass, 0-34 m), chemoautotrophic production accounted for ~7 gC m^2 yr^{-1}, compared to an estimated mean annual photoautotrophic production of 180 gC m^2 y^{-1}. Chemoautotrophy in WW samples supported by AO, UO or NO was the equivalent of 0.91, 0.06, 0.13 nmol C L^{-1} d^{-1}, while it was the equivalent of 0.37, 0.21 and 0.08 nmol C L^{-1} d^{-1} in samples from the CDW water mass. Chemoautotrophy coupled to AO+UO accounted for ~124% and ~55% of measured C fixation rates in these water masses, while chemoautotrophy coupled to complete nitrification (AO+UO+NO) accounted for ~128 and ~60% of measured C fixation rates. The mean turnover times for nitrite pools base on NO were 138 ± 35 d and 15 ± 3 d in WW and CDW samples, respectively. The rate of nitrite production from AO+UO in WW and CDW samples was 503 ± 233 and 24 ± 7 nmol L^{-1} d^{-1}, respectively. The replacement time for the nitrite pool in the WW water mass by AO+UO calculated from these averages is 33 d while it is 9 d in the CDW. These calculations suggest the possibility of an additional sink for nitrite in the WW.

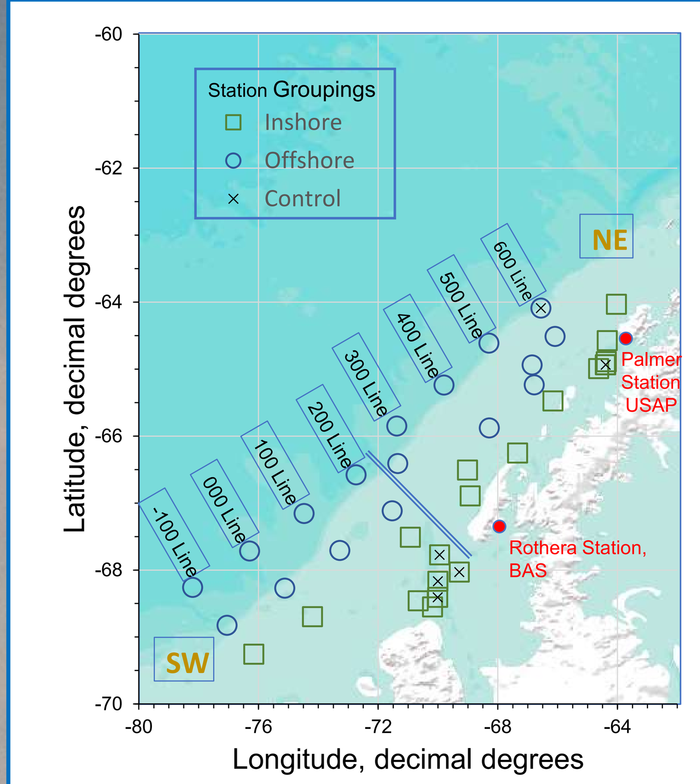


Figure 1. Station locations

INTRODUCTION

Nitrification is a globally important biogeochemical process, helping to remove excess biologically available nitrogen from the ocean via coupled nitrification-denitrification (Doney 2010, Hutchins and Capone 2022). Nitrification is a two step process, with the first step, oxidation of ammonia to nitrite performed primarily by the Thaumarchaeota, a group of marine prokaryotes (Konneke, Bernhard et al. 2005, Treusch, Leininger et al. 2005, Prosser and Nicol 2008, Ward, Arp et al. 2011), The second step, oxidation of nitrite to nitrate is performed by Bacteria, primarily of the *Nitrospina* lineage.

Thaumarchaeota and *Nitrospina* are abundant in in Antarctic coastal waters (DeLong, Wu et al. 1994, Massana, Taylor et al. 1998, Murray, Wu et al. 1999, Tolar, Ross et al. 2016). Both groups are chemoautotrophs. Chemoautotrophs use the energy they gain from chemical reactions, rather than light energy, (here oxidation of ammonia or nitrite), to reduce dissolved inorganic carbon (DIC) to biomass (organic carbon, OC).

In addition to producing organic matter by a pathway that is distinct from photosynthesis, and contributing organic C to support the microbial loop food chain in the Dark Ocean, nitrification has other geochemical consequences. It can produce nitrate in the photic zone, violating one of the major tenets of the "new production" paradigm for calculating C export fluxes (Yool, Martin et al. 2007). Partially oxidized nitrogen compounds like nitrous oxide (N_2O) are produced by both reaction pathways. N_2O is a powerful greenhouse gas. Another consequence of ammonia oxidation (AO herein after) is the production of reactive oxygen and nitrogen species (Kim, Park et al. 2016) at depths well below the photic zone where these species are produced photochemically (including by photosynthesis), (Diaz, Hansel et al. 2013). Oxidation of ammonia (ammonium) to nitrite releases H^+ ions. While this can be important in water bodies receiving ammonia-rich waste, it is not a major contributor to ocean acidification. Finally, Thaumarchaeota are likely the most abundant organisms on earth, accounting for up to 40% of bacterioplankton in polar waters and the deep sea. Although they are abundant, we know relatively little about their activity.

Participation on the Palmer LTER cruise LMG1801 provided us with an opportunity to conduct experiments to learn more about the factors controlling the abundance, distribution and activity of Thaumarchaeota in continental shelf and slope waters west of the Antarctic Peninsula. (Figure 1). In addition to nitrification, other processes that might result in the incorporation of inorganic C into organic matter include anaplerotic biochemical reactions and chemoautotrophy supported by other redox reactions, e.g. sulfide oxidation (Shanks and Reeder 1993). Similarly, there are also other sources of nitrite to Antarctic coastal waters, including incomplete reduction of nitrate by phytoplankton (Lomas and Lipschultz 2006, Mordy, Eisner et al. 2010) and photochemical reactions (Kieber, Li et al. 1999). This poster presents the results of our efforts to compare measurements of chemoautotrophic incorporation of C into biomass in the dark with estimates derived from measurements of the oxidation of ammonia and nitrite. Our objectives on this cruise were to address the following questions:

1) How tightly are the steps of nitrification coupled in Antarctic coastal waters?

2) What is the contribution of nitrification to chemoautotrophy in aerobic Antarctic coastal waters?

Table 1. Summary of chemoautotrophy measurements. Rates are given in in units of nmol C L^{-1} d^{-1}, ratios are expressed as percentages of the measured carbon fixation rate in the same sample. AO-, UO-, and NO-fueled are the calculated chemoautotrophic carbon fix rates based on ^{15}N supplied as Ammonia, Urea or Nitrite in all samples from the water masses indicated. Measured nitrogen oxidation rates were converted to C incorporation using the ratios 0.0423, 0.0368 and 0.0103 moles of C fixed per mol ^{15}N oxidized for ammonia, urea and nitrite, respectively. These conversion factors are taken from literature values of cell yields of Thaumarchaeota growing on ammonia (Konneke et al. 2005, Walker et al. 2010, Qin et al. 2014, Bayer et al. 2016) or urea (Qin et al. 2014, Bayer et al. 2016) with cells produced converted to C equivalents using 9 fg C $cell^{-1}$ for Thaumarchaeota (Berg et al. 2015). Chemoautotrophy fueled by nitrite oxidation was calculated from protein yields of nitrite oxidizers growing on nitrite (Nowka et al. 2015) converted to C equivalents by assuming that protein is 50% C and that nitrite oxidizer biomass is 50% protein. Ratios in the two right-hand columns (expressed as percentages) were only calculated for samples with measurements of all 4 variables (AO, UO, NO and C fixation).

Water Mass	Statistical Parameter	AO, nmol L^{-1} d^{-1}	UO, nmol L^{-1} d^{-1}	NO, nmol L^{-1} d^{-1}	Measured Carbon fixation, nmol C L^{-1} d^{-1}	Carbon fixation linked to AO, nmol C L^{-1} d^{-1}	Carbon fixation linked to UO, nmol C L^{-1} d^{-1}	Carbon fixation linked to NO, nmol C L^{-1} d^{-1}	Carbon fixation linked to AO+UO+NO, nmol L^{-1} d^{-1}	(Carbon fixation from AO) / (measured rates), %	(Carbon fixation from complete nitrification) / (measured rates), %
	Precision	2.2	0.3	4.6	0.3						
	LOD	**4.28**	**0.60**	**9.01**	**0.57**						
WW	Count	79	74	60	14	79	74.00	60	55	14	14
Samples from 35-100 m	Mean	21.6	1.7	12.5	1.7	0.9	0.06	0.1	1.0	**124**	**128**
	Median	9.0	1.4	8.3	1.7	0.4	0.05	0.1	0.6	25	42
	Max	158.1	6.7	53.3	4.0	6.7	0.25	0.5	5.4		
	Min	0.0	0.0	0.0	0.1	0.0	0.00	0.0	0.0		
	Stdev.s	35.0	1.5	13.2	1.3	1.5	0.06	0.1	1.2		
CDW	Count	73	74	60	16	73	74.00	60	50	16	16
175-1000 m	Mean	8.8	5.6	7.6	1.1	0.4	0.21	0.1	0.5	**55**	**59**
	Median	5.1	1.7	4.7	0.3	0.2	0.06	0.0	0.3	48	23
	Max	62.2	120.3	81.1	9.9	2.6	4.43	0.8	3.0		
	Min	0.7	0.3	1.2	0.1	0.0	0.01	0.0	0.1		
	Stdev.s	10.8	18.9	13.8	2.4	0.5	0.70	0.1	0.6		

Figure 2. Relationship between the abundance of *Nitrospina* 16S rRNA genes and the rate of nitrite oxidation measured using $^{15}NO_2^-$

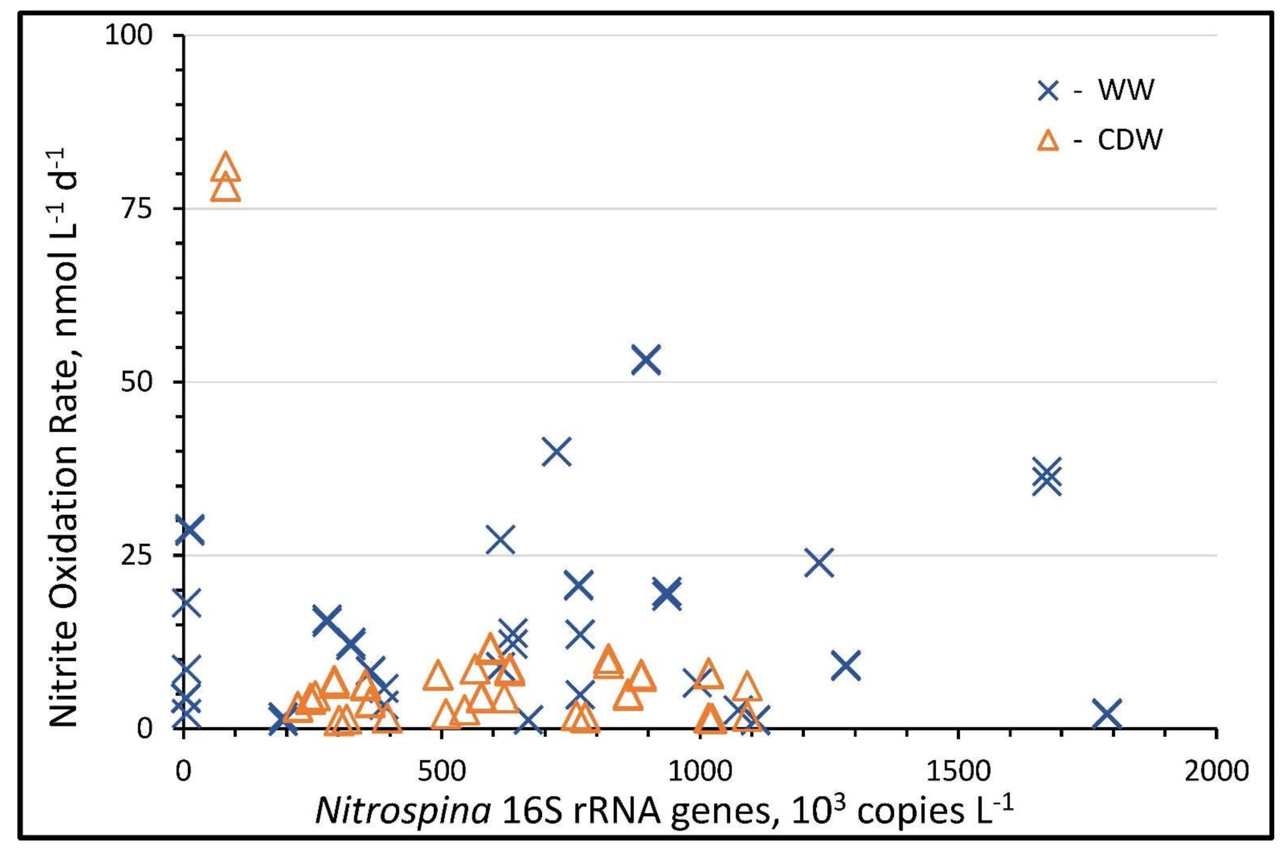


Figure 3. Production of nitrite from AO + UO versus consumption by NO. Panel A: rates of nitrite production and consumption measured using ^{15}N-labeled NH_4+ and NO_2^-. Panel B: turnover time of the nitrite pool calculated from production and consumption rates in panel A and *in situ* pool size.

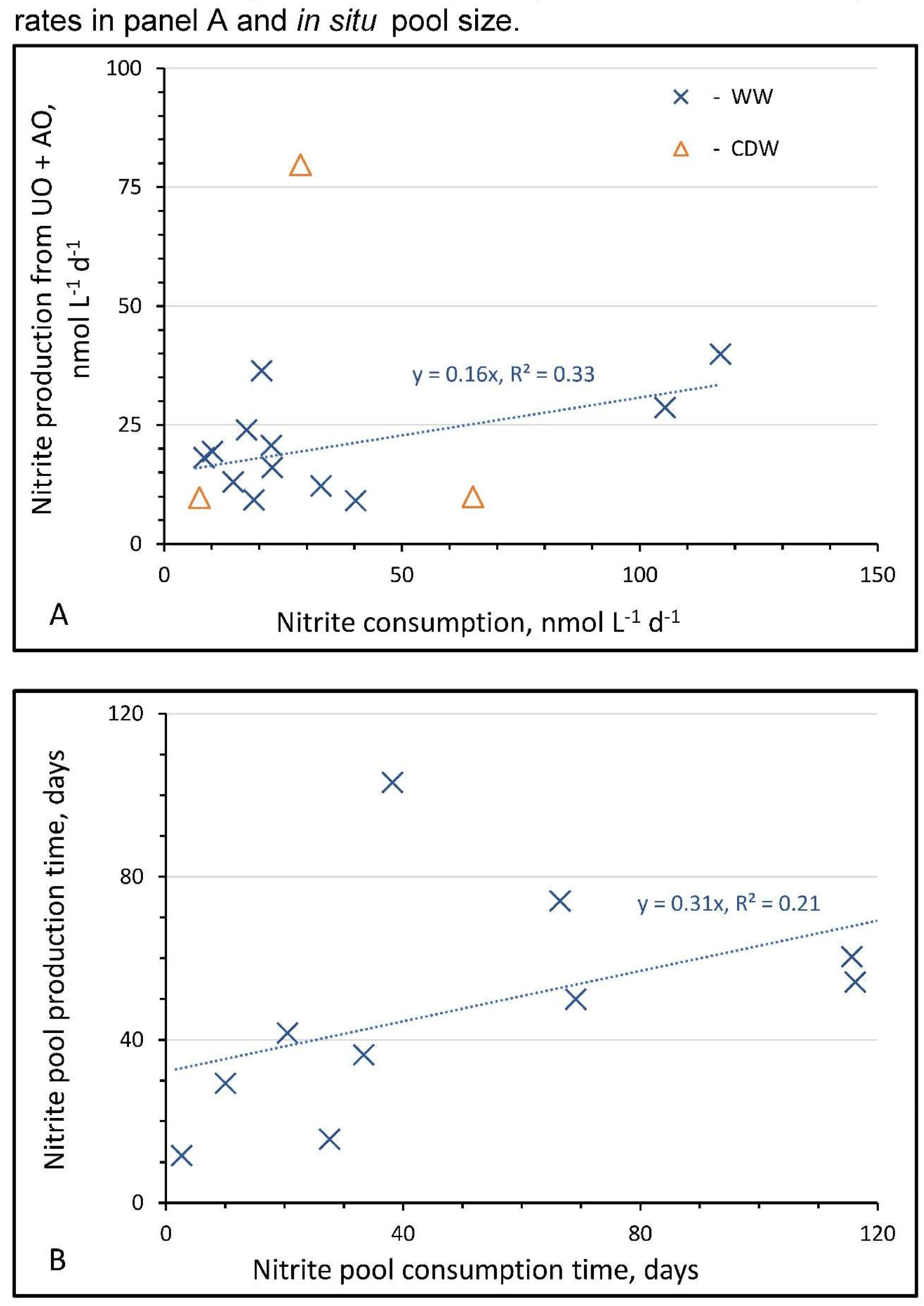
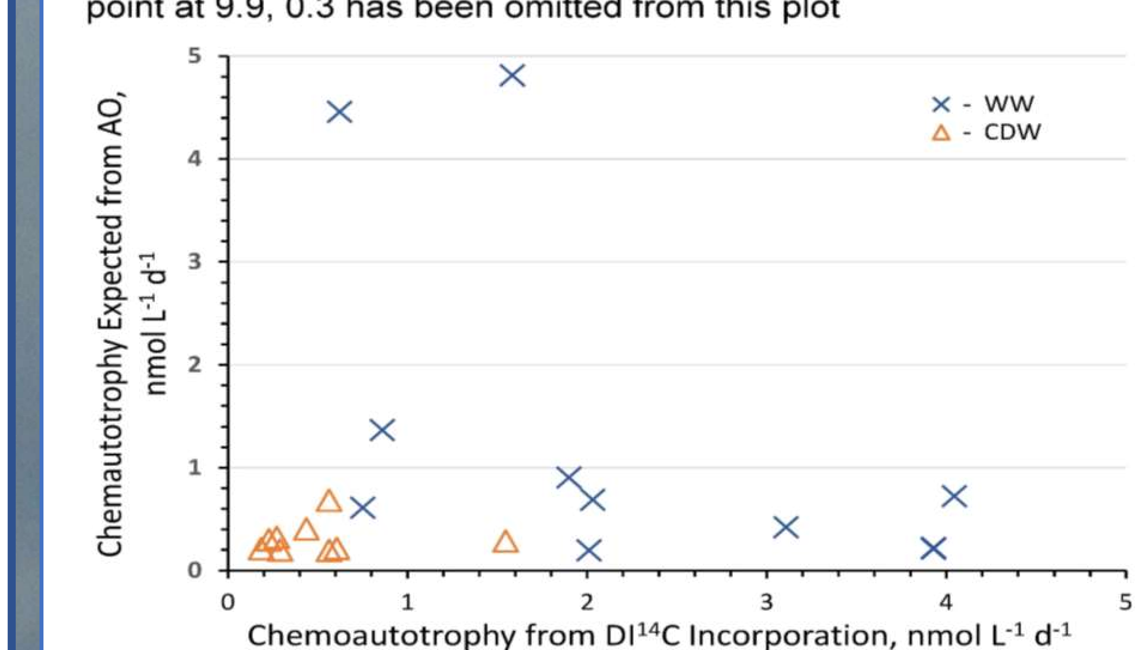


Figure 4. Comparison of chemoautotrophic production measured as $DI^{14}C$ incorporation into biomass with chemoautotrophic production calculated from ammonia oxidation rates. One CDW point at 9.9, 0.3 has been omitted from this plot



CONCLUSIONS

1) How tightly are the steps of nitrification coupled in Antarctic coastal waters?

Figure 2 reveals little correlation between the abundance of putative nitrite oxidizing bacteria (*Nitrospina*) and rates of nitrite oxidation. Other groups or processes may be contributing to nitrite oxidation, or regulation of rates may depend on other factors (substrate pool size). The relationship between turnover rates of nitrite pools shown in Figure 3 suggests this is the case, at least for the WW water mass.

2) What is the contribution of nitrification to chemoautotrophy in aerobic Antarctic coastal waters?

Table 1 shows that, on average, carbon fixation fueled by the oxidation of N contained in NH_4^+ and urea can account for most of the energy need for chemoautotrophic C fixation. However, Figure 4 shows that the processes are not tightly coupled in any given sample.

ACKNOWLEDGMENTS

We thank the officers and crew of the ARV Laurence M. Gould, the staff of Raytheon Polar Services Company, and personnel affiliated with the Palmer LTER (funded through NSF PLR 1440435) for their support during cruise LMG1801 and for subsequent access to project data. We would also like to thank S. Rauch at BCO-DMO for her assistance in archiving the data from this project. JTH would like to thank T. Hastings for just being there. This work was supported by the US National Science Foundation through grants OPP 1643466, (to JTH) and OPP 1643354 (to BNP). JTH's participation in this meeting is supported by contract BD-H-GL-CA035 from KBR, Inc.