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Modeling the Distribution and Type of High-Latitude Natural Wetlands for Methane Studies

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Why model wetlands?

- Natural wetlands are the largest CH_4 source now and in the past.
- Wetland distribution and methane emissions sensitive to interannual and long term climate variation.
- High latitude wetlands comprise half of global wetland area and produce about one third of annual methane emissions.
- Wetland distribution and CH_4 production are likely to change with at high latitude warming.
- Latitudinal bias in wetland area could cause underestimation of the impact of amplified polar warming on modeled wetland methane emissions.
- Modeling wetlands is critical to predicting future changes in wetlands and their CH4 emission.

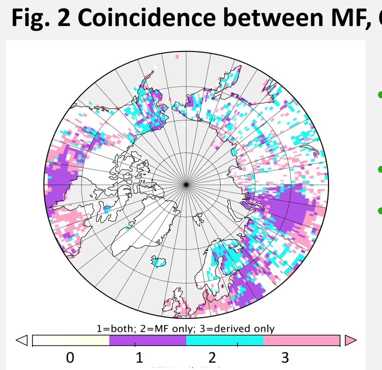
1. Modeling wetland distribution: can we predict wetland locations?

Background, Data and Methods: Methane-wetland models use several approaches for predicting methane-producing areas, with a wide range of results (Melton et al 2013, Wania et al 2013; Riley et al 2011, Marthews et al 2015). We use two simple modeling approaches using landscape slope (Verdin 2011) and modeled water table depth (Fan et al 2011), and compare the results to the observed wetland distribution based on vegetation and soil type/phase from Matthews and Fung 1987 (MF87).

- **Overlay method**: regions meeting *a priori* slope and water table depth criteria, similar to the method used by UVic (Wania et al. 2013)
- **Cluster method**: hierarchical clustering, which identifies its own criteria based on the input data (Manning et al 2008)
- Wetland fractions at 1 degree are fractional coverage of water table depth <=25cm

Wetland Locations

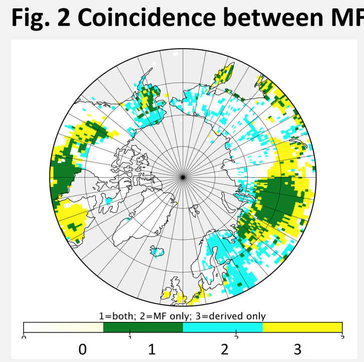
Fig. 2 Coincidence between MF, Overlay



1=both; 2=MF only; 3=overlay only

- Realistic wetland locations near Hudson Bay, eastern Europe, and western Siberia
- Identifies some nonflooded wetlands in Alaska.
- Too many wetlands in Canada and Europe, too few in Scandinavia and Russia

Fig. 2 Coincidence between MF, Cluster



1=both; 2=MF only; 3=cluster only

- Identifies large wetland complexes near Hudson Bay and western Siberia
- Identifies some nonflooded wetlands in Alaska
- Puts wetlands mainly in large continuous swaths of Canada and Eurasia

Wetland Areas

Fig. 3 MF87 Wetland Fraction

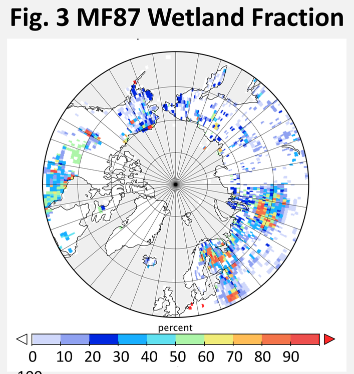
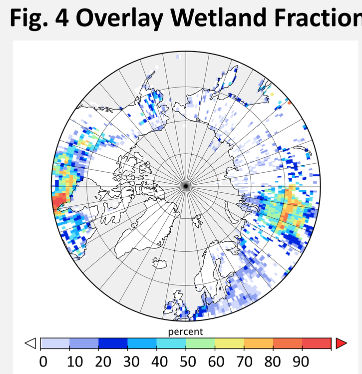
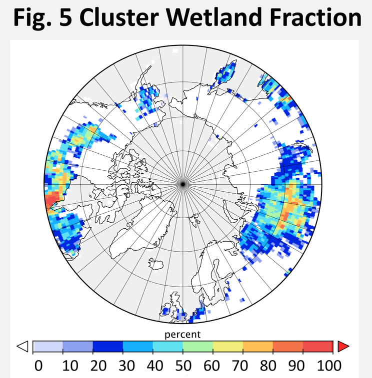


Fig. 4 Overlay Wetland Fraction



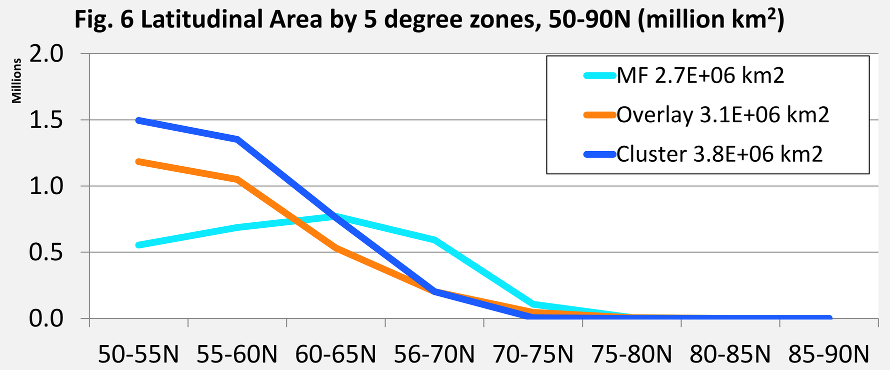
- Reasonable spatial pattern
- Western Siberia correct magnitude but too far south
- Overestimates near Hudson Bay, underestimates in eastern Europe

Fig. 5 Cluster Wetland Fraction



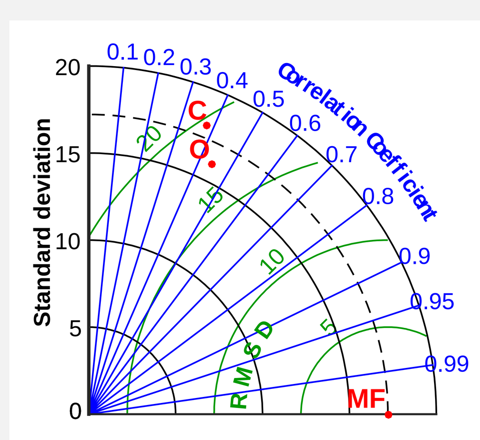
- Less agreement with observations
- Overestimates in Canada, Siberia, underestimates in Europe

Fig. 6 Latitudinal Area by 5 degree zones, 50-90N (million km^2)



- Overlay method produces more realistic areas than cluster method.

Fig. 7 Taylor Diagram Comparing Overlay and Cluster Spatial Variability



- Summary of agreement between observed and modeled wetland fractional coverage
- Overlay better correlated with observed (blue radii)
- Range of variability of overlay and cluster similar to observed (standard deviation, black arcs)
- Overlay values more similar to obs (root mean square difference, green arcs)

Discussion

- Wetland spatial distribution can be simulated with simple input variables and methodology
- Overlay method better at reproducing location, area integrals and spatial pattern of fractional coverage
- Results more realistic than wetland distributions from modeled soil moisture (Melton et al 2013)
- Overlay total area close to observed, too much area between 50-60N, too little area >60N
- Underestimates wetlands in locations with large sub-gridscale slope variability or low modeled water depth fraction
- Overestimates wetlands where modeled water table depth fraction is too large

2. Modeling wetland type: can we predict methane-relevant wetland types?

Background, Data and Methods: Wetland type, based on wetland ecosystem, soil type/phase, permafrost presence or absence, inundation dynamics, air and soil temperature, and other variables, is widely understood to strongly influence CH4 emission (e.g, MF87, Olefeldt et al 2013, Li et al 2016), yet wetland types are not are not included in methane-wetland models (e.g., Melton et al. 2013). Hierarchical clustering was used by Johnston et al (2009) to examine environmental impacts on wetland conditions, but has not been used for methane-relevant wetland classification.

- Observed wetland distribution from MF87 augmented with a suite of geophysical variables that characterize wetland environments:
  - Maximum inundation, inundation duration, annual precipitation
  - Mean annual minimum temperature, mean annual temperature range, 0-30cm annual mean soil temperature
  - Thaw season duration, snow season duration
  - Permafrost extent, ground ice content
  - 0-30cm soil organic carbon
- Algorithm constrained to produce 8 clusters
- Spatial distribution of the clusters in most common types is analyzed by examining cluster results obtained for each variable individually (individual variable clusters not shown)

Observed wetland types (Fig. 8) that occur >50˚N (Matthews and Fung)*

1. FB: cold deciduous forest
2. FB: temperate/subpolar needleleaf forest
3. FB: evergreen needleleaf woodlands
4. FB: subpolar shrubland
5. ~~FB: tropical/subtropical rainforest~~
6. NFB: tundra/bog/forb
7. ~~FS: tropical/subtropical rainforest~~
8. ~~FS: shrubland~~
9. ~~FS: tropical/subtropical seasonal forest~~
10. FS: wetlands in arid systems
11. NFS: grassland, woody cover
12. ~~NFS: tall grass, no woody cover~~
13. NFS: short grass, meadow

** FB = forested bog; NFB = non-forested bog; FS = forested swamp; NFS = non-forested swamp*

Fig. 8 Matthews and Fung Wetland Types

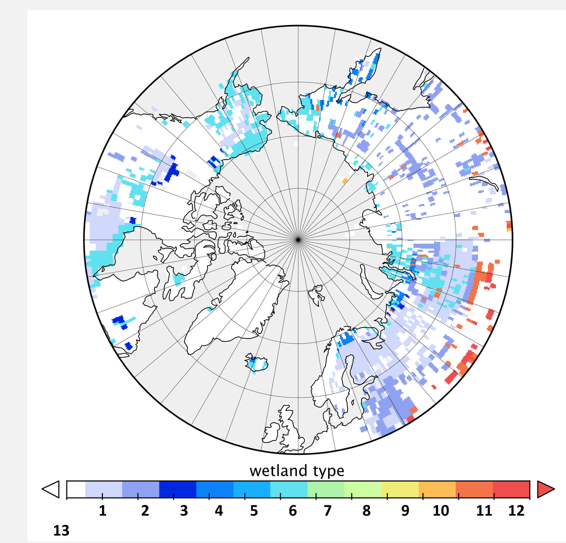
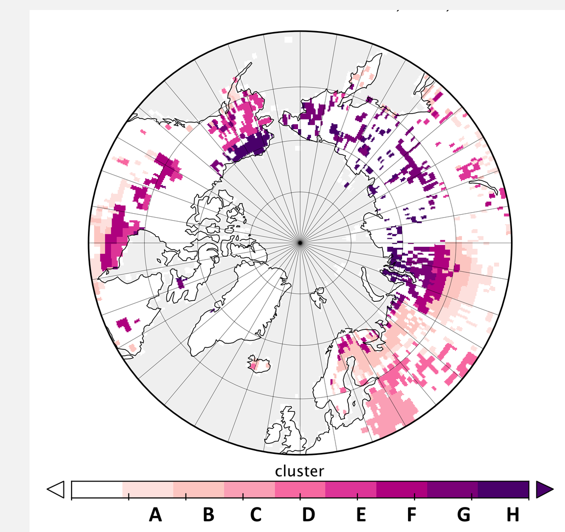


Fig. 9 Wetland-type Clusters



- Clusters occur in coherent spatial patterns
- Cluster pattern not very similar to observed types
- Clusters are more likely than observed types to occur along the same latitude band

Table 1. Percent of Total Wetland Grid Cells in Clusters Skill score: 38.0

	Type 1	Type 2	Type 3	Type 4	Type 6	Type 10	Type 11	Type 13
No. Cells	573	373	30	58	418	4	63	25
Cluster A	19.0	13.7	0.0	0.0	7.4	0.0	**52.4**	**52.0**
Cluster B	**41.9**	3.8	13.3	19.0	6.9	25.0	0.04	0.0
Cluster C	3.7	17.2	0.0	0.0	0.0	0.0	3.3	8.0
Cluster D	8.0	8.6	0.0	0.0	1.2	0.0	17.5	40.0
Cluster E	8.7	8.3	**36.7**	10.3	15.1	0.0	4.8	0.0
Cluster F	16.9	5.9	26.7	12.1	15.8	0.0	8.0	0.0
Cluster G	0.9	**31.6**	23.3	**48.3**	19.9	0.0	14.3	0.0
Cluster H	0.9	11.0	0.0	10.3	**33.7**	**75.0**	0.0	0.0
Total %	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Wetland types are distributed among multiple clusters, some with 2-3 dominant clusters
Temperature and permafrost always most important

Type 1 Cold deciduous forest: subpolar Canada, interior Alaska, NE Europe and the western Siberia
- Weaker role played by the water variables, and little contribution from soil carbon

Type 2 Temperature/subpolar needleleaf forest: eastern Europe, scattered throughout Eurasia
- Some contribution from soil carbon and inundation duration

Type 6 tundra/bog/forb: south of Hudson Bay, Canadian Arctic, coastal Alaska, Asian Arctic coast, western Siberia
- Some contribution from soil carbon
- Inundation variables have less influence

Conclusions:

- Wetland distribution has been simulated with two methods using simple variables
- Overlay method better reproduces location and fractional coverage of wetlands
- Clustering performs poorly for predicting wetland location because it overemphasizes water table depth
- All wetland types are associated with multiple clusters
- Clustering controlled primarily by temperature and permafrost
- Lesser contributions to clustering from inundation variables and soil carbon
- Cluster results provide information that may help refine methane-relevant type classification

Next Steps:

- Include fractional tree cover to help separate types based on vegetation
- Use permafrost data with better spatial variability within permafrost type
- Inundation data contains small lakes, use inundation of wetlands only
- Refine inundations metrics such as inundation fraction during thaw season
- Repeat clustering, assess role of individual variables, iterate…

References: MF87: Matthews & Fung, GBC, 1, 1987; Prigent et al., GRL, 28, 2001; Prigent et al., JGR, 112, 2007; Papa et al., JGR, 115, 2010, Beerling, D. and F.I. Woodward, Vegetation and the Terrestrial Carbon Cycle, Cambridge Univ. Press, 2001.; Manning et al., Introduction to Information Retrieval, Cambridge University Press 2008; Melton et al., Biogeosciences 10, 2013; Riley et al Biogeosci 8, 2011; Johnston et al. Ecol. Appl. 19, 2009; Marthews et al Hydrol. Earth Syst. Sci 19, 2015; Li et al Sci. Total Env. 572, 2016; Olefeldt et al GCB 19, 2013; Fan and Miguez-Macho, Clim.Dyn., 37, 2011. Rienecker et al., J. Clim., 24, 2011; Wania et al. Geosci. Model Dev. 6, 2013, Kim et al. Earth Syst. Sci. Data 9, 2017, Verdin, ISLSCP II HYDRO1k Elevation-derived Products, 2011, Hall and Riggs, MODIS/Terra Snow Cover Daily L3 Global 0.05Deg CMG, Version 6, NSIDC

Datasets: Climatological (1998-2007) annual mean max inundation and inundation duration (Prigent et al 2001, Papa et al 2007); annual min and annual range near-surface air T and total annual precipitation (Univ. of Maryland); fraction of grid box with water table depth <0.25m (Fan and Miguez_Macho), 0-30cm soil T (MERRA), (Harmonized World Soil Database, and permafrost type (Brown et al., 1998), landscape slope (ISLSCP, from HYDRO1K), freeze/thaw (Kim et al. MEaSUREs Global Record of Daily Landscape Freeze/Thaw Status, Version 4, NSIDC, fractional snow cover (MODIS, Hall and Riggs 2016)

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