Overview of Ice Dynamics Working Group

Climate and the Earth System (CLIM) Transition Workshop

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Ice Models and Statistics

- Ice sheets and sea ice play important roles in climate
- Ice sheets can have a huge impact on sea level rise
- Both ice sheets and sea ice are part of complex feedback mechanisms in climate change, affect energy balance

Working Group Participants

- **Yawen Guan: postdoc SAMSI/NC State**
- **Christian Sampson: postdoc SAMSI/UNC**
- Deborah Sulsky: applied mathematics U of New Mexico
- Won Chang: U of Cincinnati
- Alex Konomi: U of Cincinnati
- Joel Upston: U of New Mexico
- Derek Tucker: Sandia National Labs
- Anirban Mondal: Case Western
- Jenny Brynjarsdottir: Case Western
- Several others....

Focal Points

- Ice sheet dynamics
  - Data and research questions from Penn State group led by Dave Pollard and Klaus Keller (Geosciences/Earth and Environmental Systems Institute)
  - Simple, fast: DAIS, Danish Center for Earth System Science Antarctic Ice Sheet (G.Shaffer, 2014)
  - Complex, slow: PSU-3D ice sheet model (Pollard and DeConto, 2012)
- Sea ice dynamics
  - **Working group: data and research questions led by Deborah Sulsky. Model: In-house (details in her talk)**

Outline of Session

Plan:

1. Intro (5-10 mins)
2. 3 $\times$ (20 mins + 5 min discussion)
3. open discussion

Talks:

1. Deborah Sulsky: “Overview of Sea-Ice Modeling and Statistical Challenges”
2. Won Chang: “Ice Model Calibration using Zero-Inflated Continuous Spatial Data”
3. Yawen Guan: “Arctic Sea Ice Plays an Important Role in the Global Climate”

Parameter estimation working group (Tuesday): Ben Lee “Particle-based Approach for Computer Model Calibration”

Overarching Statistical Challenge

- We want to understand the behavior of the ice sheet or sea ice models
- How does the model output change as we vary inputs?
- How does the model output compare to observations?
  - Observations can be sparse
  - Observations are often indirect, that is, they are reconstructed from other sources
  - Observations may not always be aligned spatially or temporally with model output
- What does the model say about the future? Model projections:
  - Use observations to guide projections
  - Account for various uncertainties carefully

Common Challenges

Input dimensions

- There are many parameters that affect the behavior of the model
  - Can number in the hundreds
  - Slow models (e.g. sea ice model): infeasible to run everywhere
  - In practice, often only a few make a serious difference to model behavior
    - If we focus on just model behavior, things may be simplified
    - But parameter inference is of scientific interest, even without prediction
  - Parameters are often not identifiable (“over-parameterized”)
- **Working group: Adaptive sampling in the context of sea ice model. Preliminary work/ideas led by Alex Konomi**

Complicated Model Output and Observations

- High-dimensional, potentially spatio-temporal model output and observations
  - Dimension reduction approaches may be useful (Chang et al, 2014, 2016a, b; Haran et al. 2017)
- Form of the output:
  - Ice thickness ≥ 0
  - Lots of places with no ice = zero-inflated spatial data. This is computationally challenging (see for instance Recta et al. (2012))
- **Working group: Building model emulation/calibration for positive semi-continuous spatial data. Preliminary work/ideas led by Won Chang**

Data-Model Complications

- Multiple data sets from different sources: ice concentration, thickness, motion, deformation (**Deborah Sulsky's talk**)
- Observations have errors
- Models may differ from observations in systematic ways
  - No parameter setting will align the model with the data (even after accounting for measurement error)
  - Referred to as data-model "discrepancy"
  - Important to account for this carefully (Bayarri et al., 2007; Bhat et al., 2012)
- Huge number of additional uncertainties: model components, external "forcings" that impact the model, boundary conditions,...

Ice Metrics

- Leads: large fracture within sea ice, area of open water
- $\Rightarrow$ additional interactions between atmosphere and ocean
- Lead/fracture patterns are very important to behavior of sea ice
- Modeling fractures is complicated. Standard statistical methods do not work. E.g. Basic Gaussian process models tend to smooth over leads/fractures
- **Working group: Trying new “warping” ideas to solve this problem. Preliminary work/ideas led by Yawen Guan and Christian Sampson**

Summary

Many different research directions. Highlights:

- Warping ideas to analyze sea ice with fractures. Preliminary work/ideas led by Yawen Guan
- Model emulation/calibration for positive semi-continuous spatial data. Preliminary work/ideas led by Won Chang
- Adaptive sampling in the context of sea ice model. Preliminary work/ideas led by Alex Konomi
- Melt ponds work led by Christian Sampson
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References

- Schaffer, G. (2014) Formulation, calibration and validation of the DAIS model (version 1), *Geoscientific Model Development*
- Pollard, D.P and DeConto, R.M. (2012) Description of a hybrid ice sheet-shelf model *Geoscientific Model Development*
- D. Sulsky, H. Schreyer, K. Peterson, M. Coon and R. Kwok, Using the Material-Point Method to Model Sea Ice Dynamics, *Journal of Geophysical Research*
- Bayarri, Berger, Paulo, Sacks, Cafeo, Cavendish (2007) A framework for validation of computer models, *Technometrics*
- Chang, W., Haran, M., Applegate, P., and Pollard, D. (2016) Calibrating an ice sheet model using high-dimensional binary spatial data, *Journal of the American Statistical Association*
- Recta, Haran, Rosenberger (2012) A two-stage model for point-level spatial count data, *Environmetrics*