Snow dynamics impacts on temperate / high latitude climate

Proposed by IPSL (LSCE and LMD teams)
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Main project objective

⇒ Improve our understanding of snow-vegetation-atmosphere feedbacks, with the IPSL climate model (LMDZ-ORCHIDEE) and various CCI products (especially snow products)

Rationale

⇒ Climate predictions are highly sensitive to surface albedo/temperature in cold regions impacted by snow

⇒ Recent work performed in CCI-HRLC project show that a change in land cover can impact snow cover & albedo and surface temperature, inducing modifications in the air temperature, rainfall/snowfall partition leading to a positive feedback loop in the IPSL model!
Models / Tools

- Use of LMDZ-ORCHIDEE models (including multi-layer snow scheme)
Example over Siberia (coupled land-atmosphere model study):

⇒ New HRLC ⇒ reduction of tree cover up to 20% in the northern part of the domain,
+ revision of albedo scheme (snow and veg)

**New HRLandCover minus old MRLandCover (mean over 2005-2014)**
Example over Siberia (coupled land-atmosphere model study):

- New HRLC ⇒ reduction of tree cover up to 20% in the northern part of the domain,
  + revision of albedo scheme (snow and veg)
- Increased the surface albedo up to 10% in annual mean (3% in summer)

New HRLandCover minus old MRLandCover (mean over 2005-2014)
Example over Siberia (coupled land-atmosphere model study):
⇒ New HRLC ⇒ reduction of tree cover up to 20% in the northern part of the domain,
⇒ Increased the surface albedo up to 10% in annual mean (3% in summer),
⇒ Decreased the air temperature up to 3 K (mainly in spring - summer)

New HRLandCover minus old MRLandCover (mean over 2005-2014)
Potential feedback loop induced by land cover /albedo changes (in the model)

- Decrease of tree cover
- Longer & larger snow cover fraction
- Higher albedo
- More snow fall in JJA
- Cooler air temperature
- Cooler surface temperature

(feedback in the model)
Specific Objectives - Approach

⇒ What does the CCI-data can tell us about the potential “LC - Snow - Climate” feedbacks over the last decades?

⇒ Can we improve such representation in the ORCHIDEE-LMDZ model?
Shrub expansion in the Arctic

Today and tomorrow:

- Arctic greening

- Shrubification (= shrub cover increase)

Frost and Epstein, 2014
Planned work

• **Data Analysis (WP1)**
  
  Consistency check/analysis between Snow Cover (mass & extent) and Land Cover dynamics and other CCI products (LST; Fire; Biomass)
  
  - CCI-SNOW (SCF and SWE): MODIS (1km, 2000 - 2020) and AVHRR (5 km, 1982 - 2018)
    Making use of SCFV (top of forest) versus SCFG (ground cover)
  
  - MR-HR Land Cover: 300 / 30 m data mapped onto PFT at 1km
  
  - LST (0.05°, 1995-2020); Fire (MODIS; 2001 - 2020); BIOMASS (3 epoch data 1990, 2010, 2018)
  
  => Analysis of the differences btw short & tall vegetation and Deciduous & Evergreen

• **ORCHIDEE model evaluation (WP1)**
  
  Evaluate the simulated snow cover dynamics (mass and extent) in ORCHIDEE using prescribed climate forcing ERA5
  
  Define a set of key “homogeneous points” for the optimisation step
Planned work

• **Model improvement (WP1 & Synergies with others projects)**
  - Account for Shrubs & the representation of Snow - Veg dynamics in ORC (Druel et al. 2019): Work in collaboration with ongoing H2020 GreenFeedback project)
  - Improving soil thermics (carbon impact on soil thermal properties; ongoing work)

• **Model optimisation (WP2)**
  - Model sensitivity experiments to identify key parameters (Moris / Sobol approaches)
  - Multi-site optimisation (local/global approaches, History Matching...) using SCF and SWE data

• **Coupled Model simulations (WP3 - not funded yet !)**
  - Use the Coupled LMDZ - ORCHIDEE model (AMIP type simulation (fixed SST, SIC)
  - Historical simulations to analyse the impact of “improved snow model” on the feedbacks
• Use of LMDZ-ORCHIDEE models (including multi-layer snow scheme)

• Use of parameter optimization / calibration tools (ORCHIDAS system)
In presence of snow:

- Partial snow cover
- Specific Energy budget for snow to model snowpack evolution
- Grid energy budget modified to account for snow impacts on albedo, surface roughness, sublimation, soil temperature, …
Snow Energy budget & Snow model

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Snow model:

- 3 layers snow model for vegetated and bare soil surfaces
- Same model for ice sheets and glaciers

Outputs:
For each layer:
- Snow temperature
- Water content
- Heat content
- Depth and thickness
- Snow density
And also:
- Snow mass and runoff
Snow cover fraction & snow albedo in ORCHIDEE

- Snow cover fraction depend on snow mass and density (Swenson & Lawrence, 2012)

\[
frac{\text{snow}}{\text{snowdepth}} = \tanh\left(\frac{\text{snowdepth}}{0.025 \cdot \text{snowrho} \cdot 50}\right)
\]
- Snow cover fraction depend on snow mass and density (Swenson & Lawrence, 2012)

\[ \text{frac}_{\text{snow}} = \tanh \left( \frac{\text{snowdepth}}{0.025 \times \text{snowrho} \times 50} \right) \]

- Albedo depends on snow age (Chalita and LeTreut 1994)

\[ \text{age}(t + \delta t) = \left( \text{age}(t) + \left( 1 - \frac{\text{age}(t)}{\text{maxsnowage}} \right) \times dt \right) \times \exp \left( -\frac{\delta_{\text{snow}}}{\text{snowtrans}} \right) \]

\[ \text{Albedo} = \text{alb}_{\text{agea}} + \text{alb}_{\text{dec}} \times \exp \left( -\frac{\text{age}}{\text{tcstsnowa}} \right) \]
Thank you...
Figure 2. Map of sites at high latitudes where shrub change has been observed and some examples of shrub change.