Are the major sources of predictabilty included in S2S systems and how well are they represented?

- Most are there MJO, Monsoon ISV, Stratopsheric Variability, Land-surface, teleconnections, (sea-ice)
- Aerosol variability not included, is there predictability associated with e.g. dust, brown clouds, volcanic aerosol (initialized, direct effects)
- We've made progress in MJO and stratosphere variability
- Need improvements in representation of teleconnections
  - Tropics -extratropics
  - Stratosphere -troposphere
- Need to assess whether ECMWF is exploiting full predictability from land-surface and sea-ice

What model developments are need to improve … ?

- Ongoing need to develop physics to improve both basic state and variability, recognizing the importance of the basic state for teleconnections.
  - Air-sea coupling, vertical ocean resolution;
  - Diurnal cycle over land;
  - Gravity waves and orographic and non-orographic drag;
  - Land-surface processes;
- Close energy and momentum budgets;
- Data assimilation for S2S – particularly coupled data assimilation in the tropics (e.g. fluxes).

Tropical variability

- Convective processes, capturing vertical profiles of heating moistening, and their variability
- Diurnal cycle of SST and air-sea interaction
  - Feedback of diurnal cycle on atmopshere?
- Diurnal cycle in Maritime Continent
  - Land-sea breezes
- Stochastic schemes can increase spread and improve reliability
- Should physics necessarily see the grid-scale?

Stratospheric Variability

Depends on interaction between mean state and upward propagating Rossby Waves

- For mean state key uncertainty is gravity wave drag
  - Trace gases distributions may be important for some biases
- Rossby Wave- generation depends on representation of tropopsheric variability, including but not limited to
  - tropical heating errors
  - Extra-tropical mean state biases
- Can predict stratosphere, but coupling to troposphere not well represented
    - Theory not well understood, S2S and other hindcast datasets useful tool to explore as this is the appropriate timescale
- Initialization above 40km is poor, particularly for winds

Land surface and cryosphere

- Likely increase in complexity in land-surface schemes, need to balance potential introduction of new biases vs improvement in representation feedbacks
- Particular components to think about
  - Urban areas
  - Consistency between sea-ice in surface scheme and sea-ice models
- Need a proper representation of uncertainty in both model and initialization
- More attention to initialization and consistency between hindcasts and forecasts

Teleconnections?

- Diagnosis of relative contributions of errors tropical heating source, mean state and extratropical processes in representing teleconnections
  - Vertical and horizontal structure of heating
  - Wave breaking and blocking processes
- Tropics – extratropics
  - Response to midlatitude forcing
  - Direct interactions (e.g. extra-tropical waves and monsoon flow)

What kind of experimentation would be useful to explore these issues?

- Nudging and bias correction experiments
  - Bias corrections based on fixed forcing from a nudging experiments to and explore the impact on teleconnections pathway.
  - Relaxation of limited regions to observations to explore of tropical forcing in extra-tropical variability (e.g. relaxation over Maritime Continent)
- Process studies (e.g. time depend vs climatology aerosol
- Explore impact of physics changes on S2S skill as part of development process (or as a research exercise)
- Identification of flow dependent errors using analysis increment.
- Comparison of LIM constructed from reanalyses and model
  - Especially for e.g day 0-5 forecasts and e.g. day 20-25 lead time

How well is model uncertainty represented?

- Closer integration between development of model components and the stochastic parameterization;
- We need to explore the representation of uncertainty in ocean/sea-ice/land-surface;
- Improved understanding of impact of stochastic parametrization on the model climate and modes of variability
- Exploit S2S to explore model uncertainty issues

How can we estimate predictability and what improvements might we realistically expect over the next 10 years?

- develop better understanding flow dependent predictability and predictive skill; is the spread flow dependent enough
- It would be useful to compare estimate of potential predictability of different EPSs.
- Do initial conditions capture the uncertainty relevant for S2S timescales – consistent perturbation strategies