Elmer/Ice adjoint inverse methods

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Re-organisation of solvers related to adjoints inverse methods in Elmer/Ice in Spring 2020 (still in progress)

- Motivations
  - Many individual developments for SSA, Stokes, mass conservation **not documented**, **fully versioned** and implying some **code redondancy**.
  - I had a bit of time due to covid-situation to wrap-up long standing promises….

Documentation is online with the Elmer/ice sources:

- https://github.com/ElmerCSC/elmerfem/tree/elmerice/elmerice/Solvers/Documentation
- In makdown, visible on github by can generate a nice pdf
- List of old solvers and their replacement with current status available here
  - https://cloud.univ-grenoble-alpes.fr/index.php/s/AHCwsgKgjWimqdG

	Existing solvers	Replacement/Planned	Comments	Possible with
	AdjointSSA_AdjointSolver.F90 AdjointSolver.F90	Adjoint_LinearSolver.F90	Adjoint code for the linear system resolution Automatic detection of Dirichlets conditions; No need to save loads in the direct solver; How to deal with periodic conditions?	Any? Stokes, SSA, Thickness
Cost solver that depends on the output of a direct solver; and should be run before the adjoint of linear system	AdjointSSA_CostDiscSolver.F90	Adjoint_CostDiscSolver.F90	discrete cost function evaluation at obs. points	Any? Stokes, SSA, Thickness
	AdjointSSA_CostContSolver.F90 CostSolver_Adjoint.F90 (cost part)	Adjoint_CostContSolver.F90	Continuous cost function, computed as the integral of the squarred error. Regularisation will be treated by a disctinct solver	Any? Stokes, SSA, Thickness
	AdjointSSA_CostFluxDivSolver.F90	No	Cost solver based on equation for flux divergence	SSA
		AdjointStokes_CostFluxDivSolver.F90	TO DO: WRITE the equivalent for STOKES	
	AdjointSSA_CostTaubSolver.F90	No	Penalise first patial derivatises of Tau_b	SSA
		AdjointStokes_CostTaubSolver.F90	TO DO: submit Stokes equivalent	
Reg. Solver that depends only on the optimised variable	AdjointSSA_CostRegSolver.F90 CostSolver_Adjoint.F90 (reg. Part)	Adjoint_CostRegSolver.F90	Regularisation based on a priori value or penalisation of 1rts spatial derivaties	NA
Model specific solvers	AdjointSSA_GradientSolver.F90	No	derivatives of parameters in the SSA solver	SSA
	AdjointSSA_SSASolver.F90	No	The direct solver that correspond to the adjoint above	SSA
	DJDBeta_Adjoint.F90	AdjointStokes_GradientBetaSolver.F90	Should we combine both solvers ? => No	
	DJDmu_Adjoint.F90	AdjointStokes_GradientViscSolver.F90	No need to make a specific solver for direct solver; we will try to stay up-to-date with Elmer legacy solvers	
		AdjointThickness_GradientSolver.F90	Adjoint of thickness solver for the mass conservation method	
Others	Optimize_m1qn3Parallel.F90	No	Update for multi-variable optimisation allow for serial optimisation See possibility for hot restart of m1qn3?	Any
	USF_CoV.F90 (User Function)	No	library of user function to deal with change of variable	Any
		Adjoint_GradientValidation.F90	Compare derivative with finite difference to validate adjoint set-up.	Any

Modification done, documentation available

No modification planned => write documentation

Store non specific solvers under elmerice/Solvers/Adjoint

Store model specific solvers under elmer/ice/Solvers/AdjointModel where model will be SSA, Stokes, Thickness, ...

Store documentation in md under elmerice/Solvers/Documentation

- Nomenclature:
  - Adjoint_...: for generic solvers that are independent of the direct problem
    - Sources under elmerice/Solvers/Adjoint
      - Adjoint_GradientValidation
      - Adjoint_LinearSolver
      - Adjoint_CostDiscSolver
      - Adjoint_CostContSolver
      - Adjoint_CostRegSolver
  - Adjoint[ModelName]_: for solvers specific to a direct solver (Stokes, SSA, …)
    - Sources under elmerice/Solvers/Adjoint[ModelName]
      - AdjointSSA_SSASolver
      - AdjointSSA_GradientSolver
      - AdjointSSA_CostFluxDivSolver
      - AdjointSSA_CostTaubSolver

- Fully documented under elmerice/Solvers/Documentation
  - Please contribute to improve this documentation and report/correct errors, mistakes, inaccuracies…

- SSA examples updated from Elmer/Ice Oslo 2016 under **elmerice/examples/SSA_Inverse_Methods**
  - Inversion of friction coefficient Mac Ayeal synthetic test case
  - Inversion of ice viscosity for the Ronne-Filchner ice shelf

- Validation/usage examples:
  - **elmerice/examples/Adjoint_CostRegSolver**/

- **What's new?**
  - In many solvers some keyword have been updated to be more meaningfull with different direct solvers
  - Solvers that required to have a dumy variable to create required structured or didn't need bandwith optimisation have this hardcoded; so no need to declare this anymore.
    - => see the doc and test cases to update your steups.

- Optimize_m1qn3Parallel:
  - Works in serial
  - Can take a variable with more than 1 dof for the optimisation => e.g. joined inversion of friction and viscosity

- Adjoint_LinearSolver (replcament for AdjointSolver and AdjointSSA_AdjointSolver)
  - Compute the adjoint variable
  - Adjoint code for linear system solution and Dirichlet conditions
  - => code more consistent with direct implementation and automatic detection of Dirichlet conditions=> no need to set Dirichlet conditions for the adjoint variable anymore

- Adjoint_CostDiscSolver:
  - Compute the cost function as a discrete sum of the error at the data location
  - => do not need to interpolate data on the mesh; better if there is too much missing values in the data set.
  - Has to find in wich element the data is to interpolate model results at the exact data location
  - Can be used with SSA; Stokes
  - Efficient Elmer built-in scheme in 2D; but slow in 3D; Data can be pre-processed in 2D if working with an extruded footprint

- AdjointSSA_CostTaubSolver:
  - Alternative regularisation; Penalise first derivatives of basal drag instead of the friction coefficient itself.
  - Will provide the same for Stokes

- To do list:
  - Put a warning in deprecated solvers and remove these solvers in the next release
  - Document solvers for Stokes and provide test cases (similar to SSA; MacAyeal and Ronne-Filchner)
  - Commit solvers and provide test cases for the mass conservation method (adjoint of thickness solver)
  - Update »automatic tests » to check consistency
  - Update Elmer/Ice sheet (Greenland) .sif file to comply with new solvers
  - Provide .sif file for joined inversion of friction and viscosity in Ronne-Filcher drainage bassin (SSA B. Urruty)
  - Finalize Stokes configuration file for Greenland (with the help of T. Zwinger, R. Geve)
  - Antarctic ice sheet SSA (B. Urruty) and Stokes (R. Gladstone)

- Some thoughts:
  - How to share results (espacially at the scale of the ice sheets), as
    - often no need to re-do the initialisation if we are using the same data sets
    - Havin an ensemble of results could be interesting to asses the uncertainties in the re-constructions
    - Could be used an Boundary or initial conditions for other applications

  - Please help to improve the documentation, report failing cases etc… and contribute to the implement new set-up.

- Inverse methods in Elmer/Ice:
  - We will be more or less set with the codes now
    - Still a lot of science to do on the regularisation (or Background); don't take what we do now (Tikhonov regularisation) as the best solution; more thoughts to have on this…. Especially when inverting several parameters
  - Moving to 4D-Var would be very complicated without using an automatic differentiation tools….
  - Will try to set-up ensemble DA in real cases (1 psot-Doc and 1 PhD to strart this automn)