Difficulties associated with data assimilation for a coupled ocean-atmosphere system

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Introduction

- The project is concerned with the accurate estimation of global circulation with a coupled ocean-atmosphere data assimilation system;
- The objectives of the coupled framework:
  - to improve the quality of forecasts from the short to seasonal and interannual timescales;
  - Study mixed layer processes in ocean and atmosphere;
  - Take into account sea-ice interaction with the atmosphere;
- Project is cast to be applicable to real measurements
  - Comparison to observations permits a detailed validation of the coupled system
  - Lead to model improvements that improve medium-range forecasts *and* climate simulations (Rodwell and Palmer, 2007)

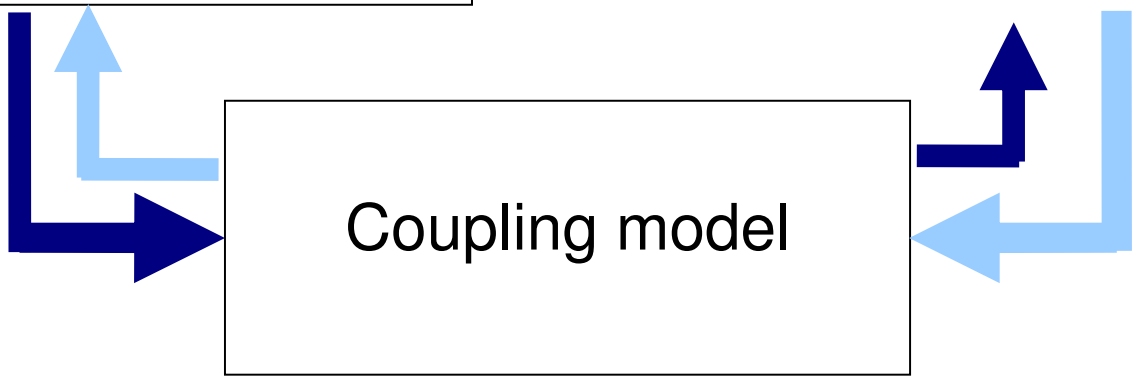
Coupled ocean-atmosphere system

NEMO ocean model

- *global configuration ;*
- *1x1 resolution (¼ x ¼ º) ;*
- *51 vertical levels ;*
- *LIM sea-ice model ;*
- *3D-Var data assimilation;*

GEM atmospheric model

- *global configuration operational at CMC;*
- *½ x ½ º resolution;*
- 4D-Var incremental data assimilation with parameter estimation



Objectives of Data assimilation

- Data assimilation is driven by the short-term forecast from the coupled model
  - maintains the model forecast close to observations;
- Assimilation can be used to estimate
  - Initial conditions of the atmosphere and ocean
  - model parameters for heat, momentum and humidity fluxes between the ocean and the atmosphere;

2009-2010 Work plan

- Implementation of the parameter estimation approach into the 4DVar-GEM system
  - To examine the ocean and atmosphere forecast quality:
    - ❖ Impact of the improved atmospheric forcing on the ocean mixed layer depth and dynamics;
    - ❖ Ocean feedback (SST, sea-ice distribution, fluxes) to the atmosphere
- Update to the coupled 4DVar-GEM-NEMOVar data assimilation system

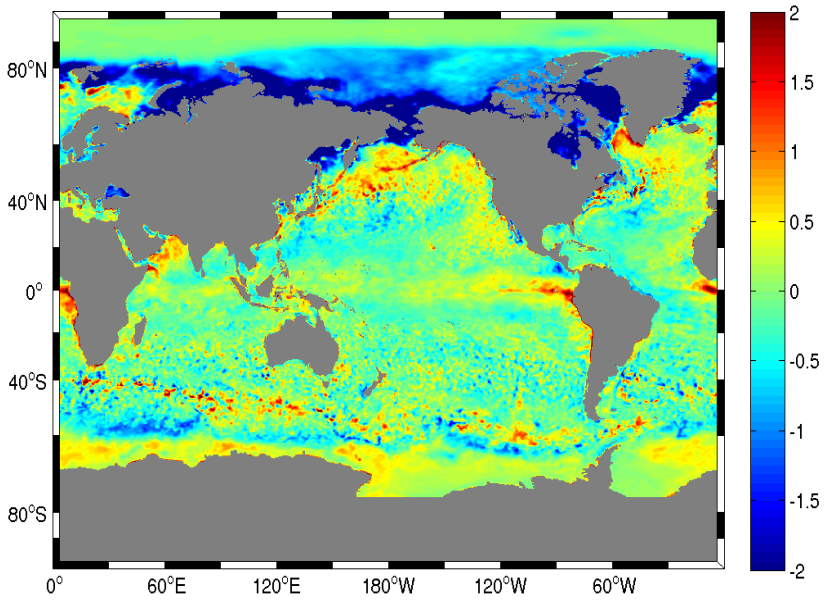
Requirements

- A coupled model demands high-quality estimation of air-sea fluxes consistent with surface measurements and model physics;
- Surface fluxes remain one of the most important source of model error:
  - Bulk aerodynamic formulae contain large uncertain-ties in the transfer coefficients;
  - Discrepancies between modeled ocean SST and observations;

Difference between CONCEPTS forecasts and CMC SST analyses

- Produce weekly 10d forecasts using ORCA025
- Important differences from CMC SST analysis can be seen
- Differences from PSY3V2R2 also present…

CONCEPTS - CMCSST for day 10 Average of
forecasts from 20090520 to 20090819



(Greg Smith, François Roy)

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GEM 4D-Var data assimilation system with parameter estimation

- Estimation problem is expressed as the minimization of the cost function

$$J(\mathbf{X},\mathbf{p}) = \frac{1}{2}(\mathbf{X}-\mathbf{X}_b)^T \mathbf{B}_X^{-1}(\mathbf{X}-\mathbf{X}_b) + \frac{1}{2}(\mathbf{p}-\mathbf{p}_b)^T \mathbf{B}_p^{-1}(\mathbf{p}-\mathbf{p}_b)$$
$$+ \frac{1}{2}(\mathbf{HM}(\mathbf{X},\mathbf{p})-\mathbf{y})^T \mathbf{R}^{-1}(\mathbf{HM}(\mathbf{X},\mathbf{p})-\mathbf{y})$$

- **Augmented** state vector :

  X= [p, q, u, v, T],

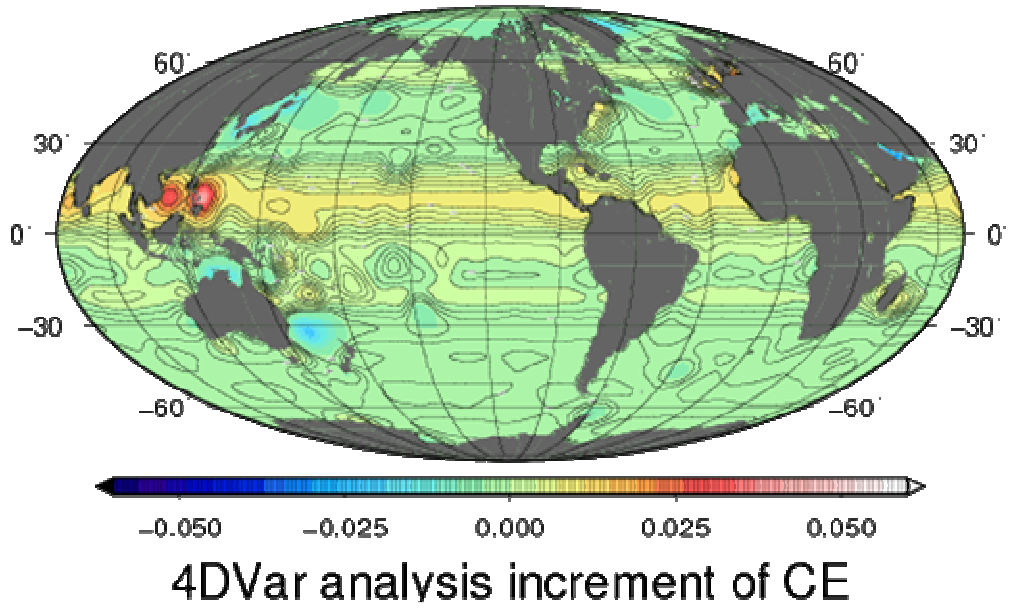
  p = [C_D, C_E , C_H, E - P]

Characteristics of the assimilation

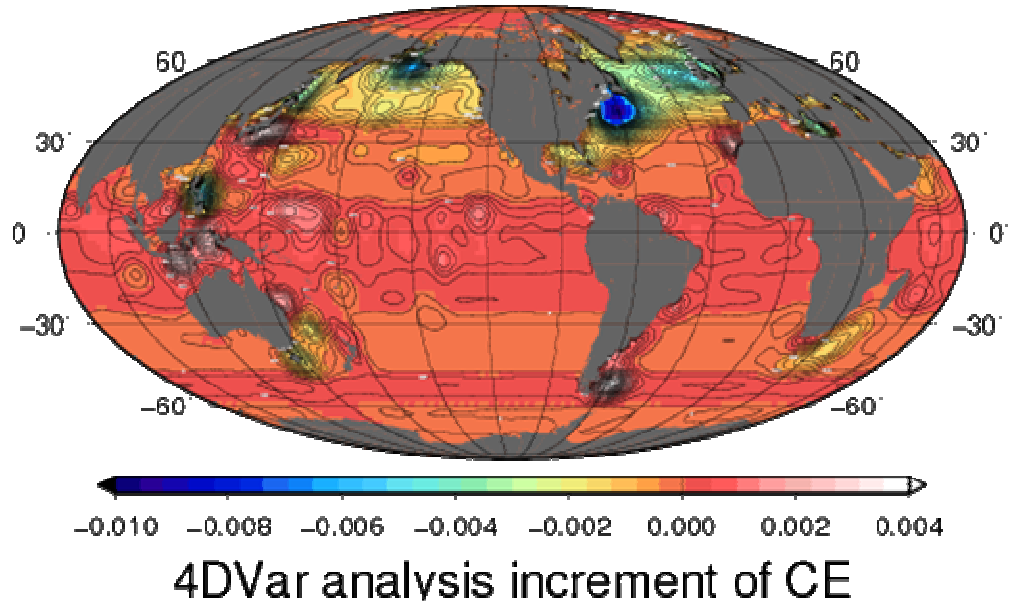
- 4D-Var assimilation for the atmospheric component only
  - Temperature observations near the surface will contribute to the estimation of the parameters (ships, buoys, etc.)
  - *Ad-hoc* error statistics for the parameter C_E: constant variance with homogeous and isotropic Gaussian correlations (L_c= 200 km)
- SST used is that provided by a separate NEMO integration
- Resolution of the atmospheric model is ~50 km
- Assimilation over a period of 4 days
- Preliminary results

4DVar analysis *parameter* increments: CE

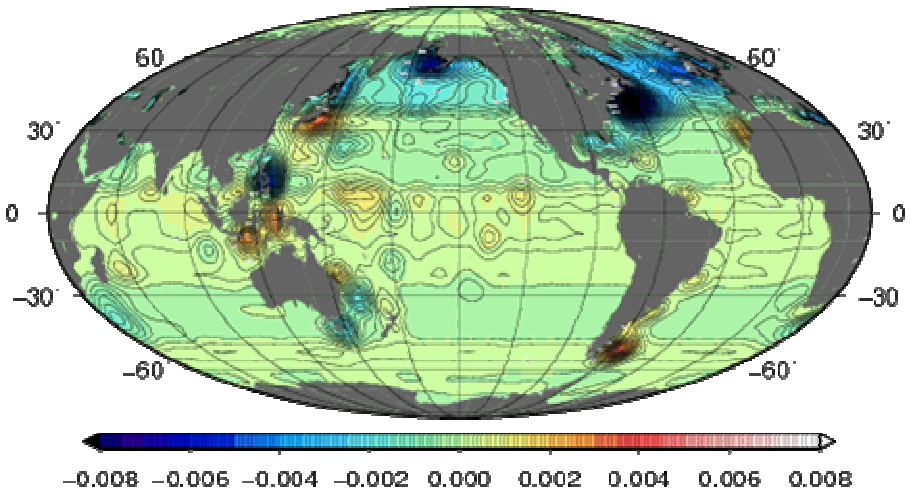
Boreal summer
Single case:
June 22, 2008



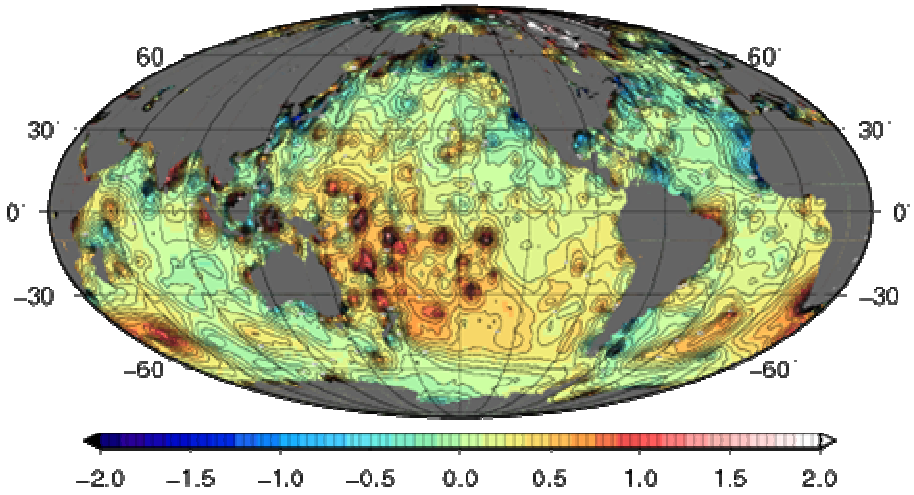
Boreal winter
Single case:
December 21, 2006



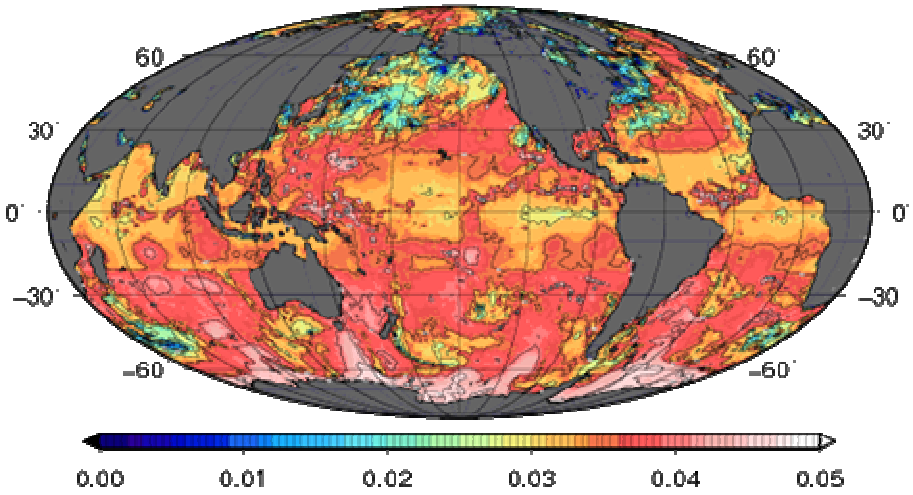
4D-Var analysis increments.



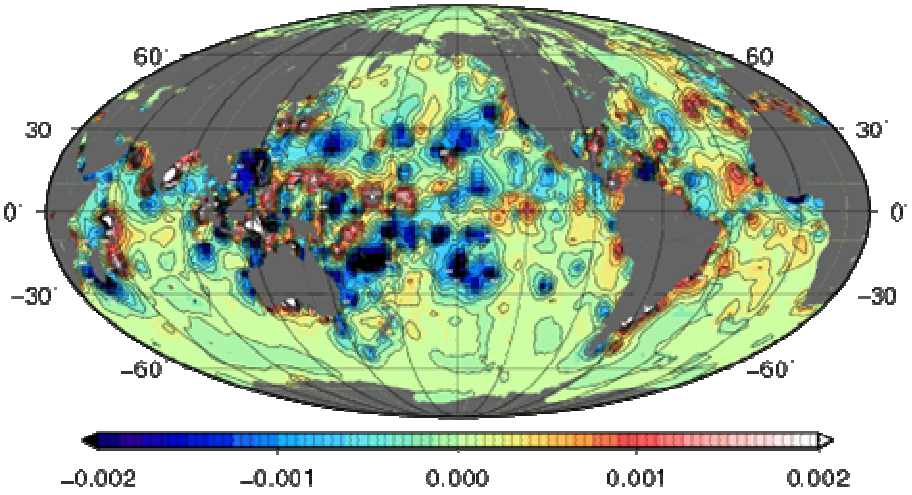
CE analysis increment



TT analysis increment



CE bulk formulation



HU analysis increment

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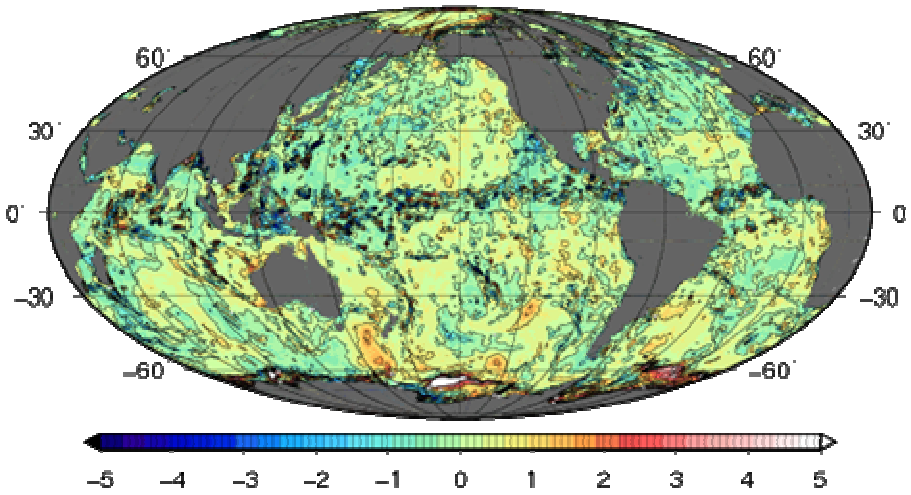
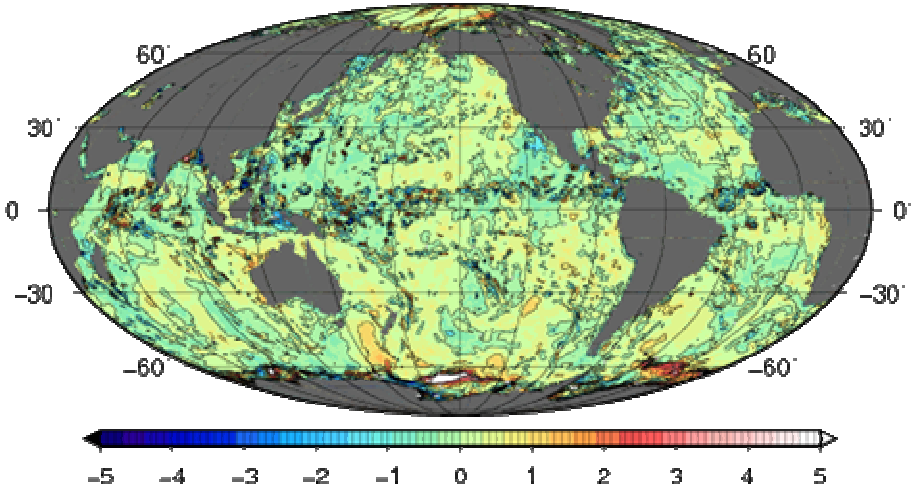
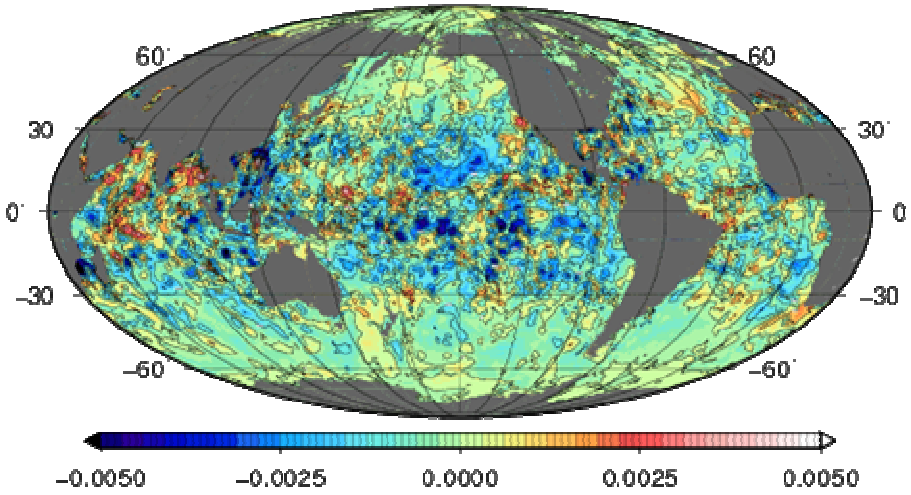
Improvement on GEM forecasts



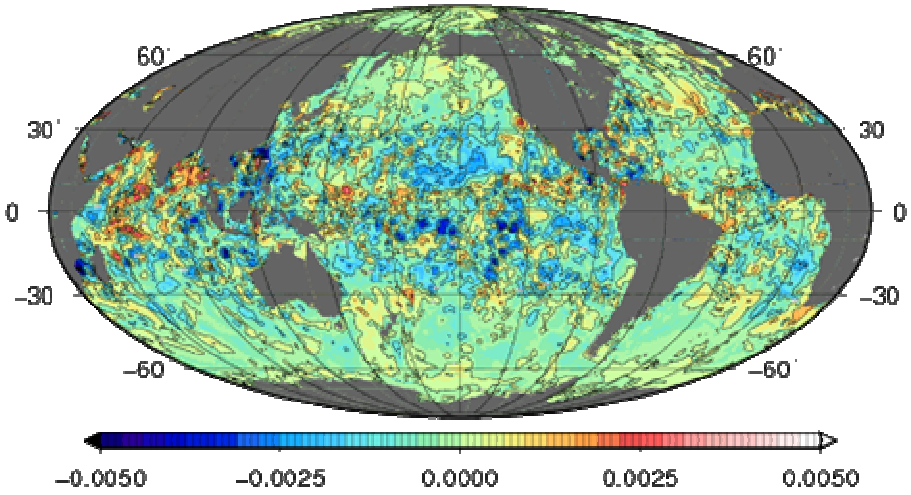
TT REF Forecast – Analysis



TT PE Forecast – Analysis



HU REF Forecast – Analysis



HU PE Forecast – Analysis

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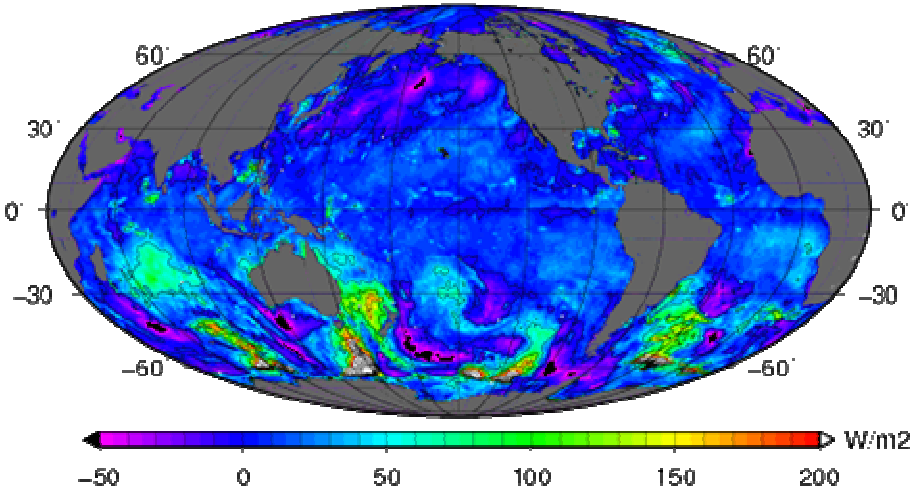
Corrected surface fluxes



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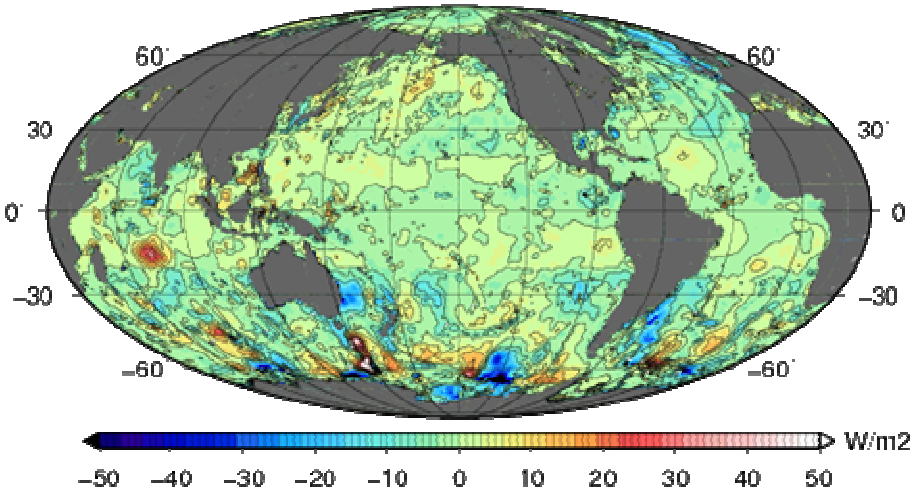

FC. PE–REF

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Current status

- Parameter estimation scheme has been implemented within GEM-4DVar atmospheric data assimilation model;
- Planned to introduce the coupled GEM-NEMO model in the assimilation suite
  - The coupled model is not yet available
  - Numerous technical issues associated with the coupling and to maintain coherence between the GOAPP and CONCEPTS work plans for the development of data assimilation for a coupled system
  - Coupled model expected to be available in September

Experiments for the coming year

- One-year assimilation with the coupled system with atmospheric assimilation only with and without parameter estimation
  - Drift (bias) problem has been noticed by other groups
  - Assess the ability of parameter adjustment to reduce the bias
- Extensive diagnostics to examine all aspects of the analyses/forecasts of the coupled systems
  - Sugiura et al. (2008) necessity to adjust several other parameterizations linked with surface fluxes

Planification for the next three years

- Proposal to the Québec government
  - to support research on regional climate (linked to the Ouranos consortium)
  - include a sub-project on data assimilation for a coupled ocean-atmosphere system
- The Earth system laboratory
  - a project to provide an Earth system modeling and assimilation facility to the academic community
  - Computing power in Canada is now in universities (Compute-Canada)
    - CLUMEQ-Québec: already installed (~8000 cores)
      - CLUMEQ-Montréal: available to users in 2011 (>18,000 cores, 2.8 Pb disk space)
    - GEM and NEMO models are already installed
    - Implementation is consistent with that of Environment Canada to be able to benefit from future developments on both sides
    - Current development is already in sync with that at EC
    - Make this available to all the Canadian atmospheric community through joint project with universities

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