Norsk institutt for luftforskning
Norwegian Institute for Air Research

Toward Assimilation of Snow Data

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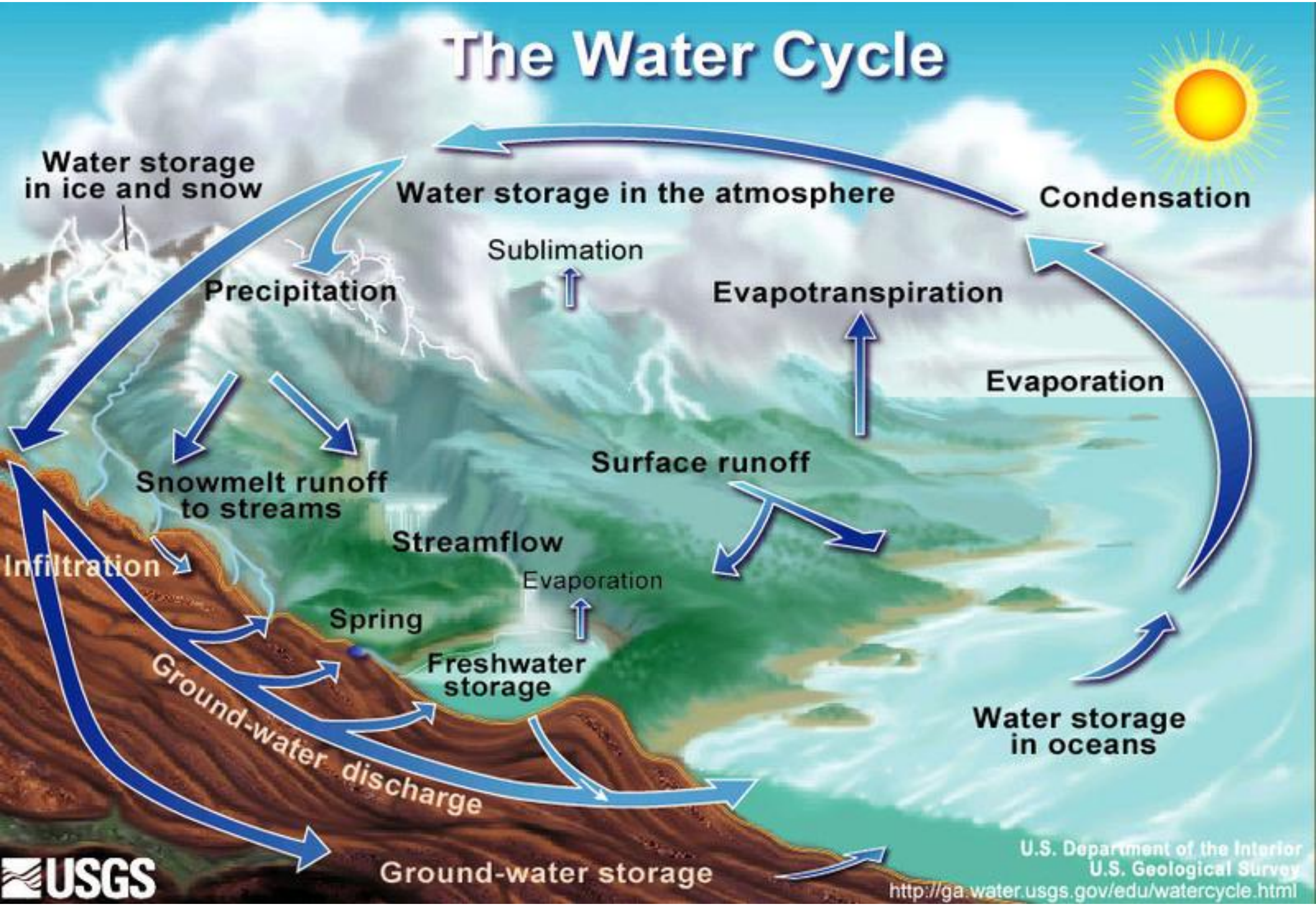
Contents:

- Importance of hydrological cycle (soil moisture, snow)
- Data assimilation (DA) idea & benefits
- Observations – input to DA
- Models – input to DA
- Development of snow DA
- GlobSNOW contribution

Importance of hydrological cycle:

- Accurate knowledge of spatial/temporal surface storages & fluxes:
    - Address wide range of important issues (societal, economic, scientific)
- Improved estimates of land surface conditions:
    - Agriculture, ecology, civil engineering, water resources management, rainfull/runoff prediction, atmospheric process studies, climate/weather prediction, disaster management



From Wikipedia

Land Water Cycle features (based on information from Paul Houser, CREW)

Input - Output = Storage Change

-> Budget

Observe and predict:

- Precipitation (solid, liquid)
- River runoff (discharge)
- Land Ice (e.g. high latitudes)
- Snow Cover (e.g. high latitudes, mountains) : GlobSNOW

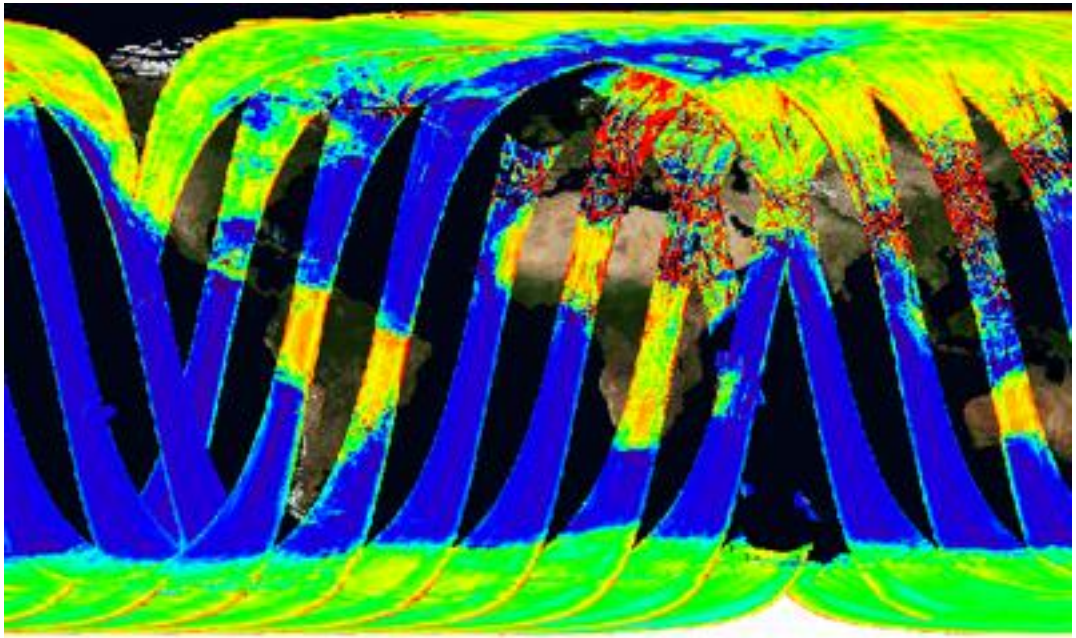
Boundary information:

- Temperature & Permafrost (e.g. tundra)
- Salinity
- Vegetation

Water Cycle:

- Moisture flux convergence
- Evolution of the ice mass (e.g. high latitudes, glaciers)
- Oceanic transports

DA idea and benefits



First SMOS data, Nov 2009

Non-calibrated brightness temperatures

Blue (low) – Red (high)

Note observational gaps

Need a model to fill in gaps (e.g. linear interpolation)

- Observational & model information with errors
- DA provides a way of combining this information in an objective way
  e.g. variational methods, minimizing a penalty function -> analysis
- DA adds value to observations: fills in gaps
- DA adds value to models: keeps on track (constrains) using observations

Lahoz *et al.* (2010): *Data Assimilation and Information*, in "Data Assimilation: Making Sense of Observations", Springer, Eds. Lahoz, Khattatov, Ménard.

Observations:

•Input to DA: in situ, remote sensing (e.g. satellite)

•Current state of the art of snow/water estimation
- •Satellite remote sensing retrievals:
  e.g. AMSR-E, SMMR, SMOS

Snow Water Equivalent (SWE) difficult to measure
Snow cover or extent common from VIS/IR remote sensing
Snow depth can be easily measured
Snow density useful for modelling & remote sensing

Note that scientists also use DA to produce analyses that can be treated as observations (common approach, e.g., reanalyses):

•Land surface models incorporating data assimilation

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Houser *et al.*, 2010,

Land Surface Data Assimilation,

in "Data Assimilation: Making Sense of Observations", Springer

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Table 1: Characteristics of hydrological observations potentially available within the next decade (see *Appendix A* for details of sensor acronyms).

Hydrological Quantity	**Remote Sensing Technique**	**Time Scale**	**Spatial Scale**	**Accuracy Considerations**	**Examples of Sensors**
Precipitation	Thermal infrared	Hourly 1day 15days	4km 1km 60m	Tropical convective clouds only	GOES MODIS, AVHRR Landsat, ASTER
	Passive microwave	3hour	10km	Land calibration problems	TRMM, SSMI, AMSR-E, GPM
	Active microwave	Daily	10m	Land calibration problems	TRMM, GPM
Surface soil moisture	Passive microwave	1-3days	25-50km	Limited to sparse vegetation, low topographic relief	AMSR-E, SMOS, SMAP
	Active microwave	3days 30days	3km 10m	Significant noise from vegetation and roughness	ERS, JERS, RadarSat
Surface skin temperature	Thermal infrared	1hour 1day 15days	4km 1km 60m	Soil/vegetation average, cloud contamination	GOES MODIS, AVHRR Landsat, ASTER
Snow cover	Visible/ thermal infrared	1hour 1day 15days	4km 500m-1km 30-60m	Cloud contamination, vegetation masking, bright soil problems	GOES MODIS, AVHRR Landsat, ASTER
Snow water equivalent	Passive microwave	1-3days	10km	Limited depth penetration	AMSR-E
	Active microwave	30days	100m	Limited spatial coverage	SnoSat, SCLP, Cryosat-2
Water level/ velocity	Laser	10days	100m	Cloud penetration problems	ICESAT, ICESAT2, SWOT, DESDynI
	Radar	30days	1km	Limited to large rivers	TOPEX/POSEIDON
Total water storage changes	Gravity changes	30days	1000km	Bulk water storage change	GRACE, GOCS, GRACEII
Evaporation	Thermal infrared	1hour 1day 15days	4km 1km 60m	Significant assumptions	GOES MODIS, AVHRR Landsat, ASTER

Difficulties with snow retrievals

- Snow is a highly variable medium
  - Large vertical variability
  - Large horizontal variability (subpixel heterogeneity)

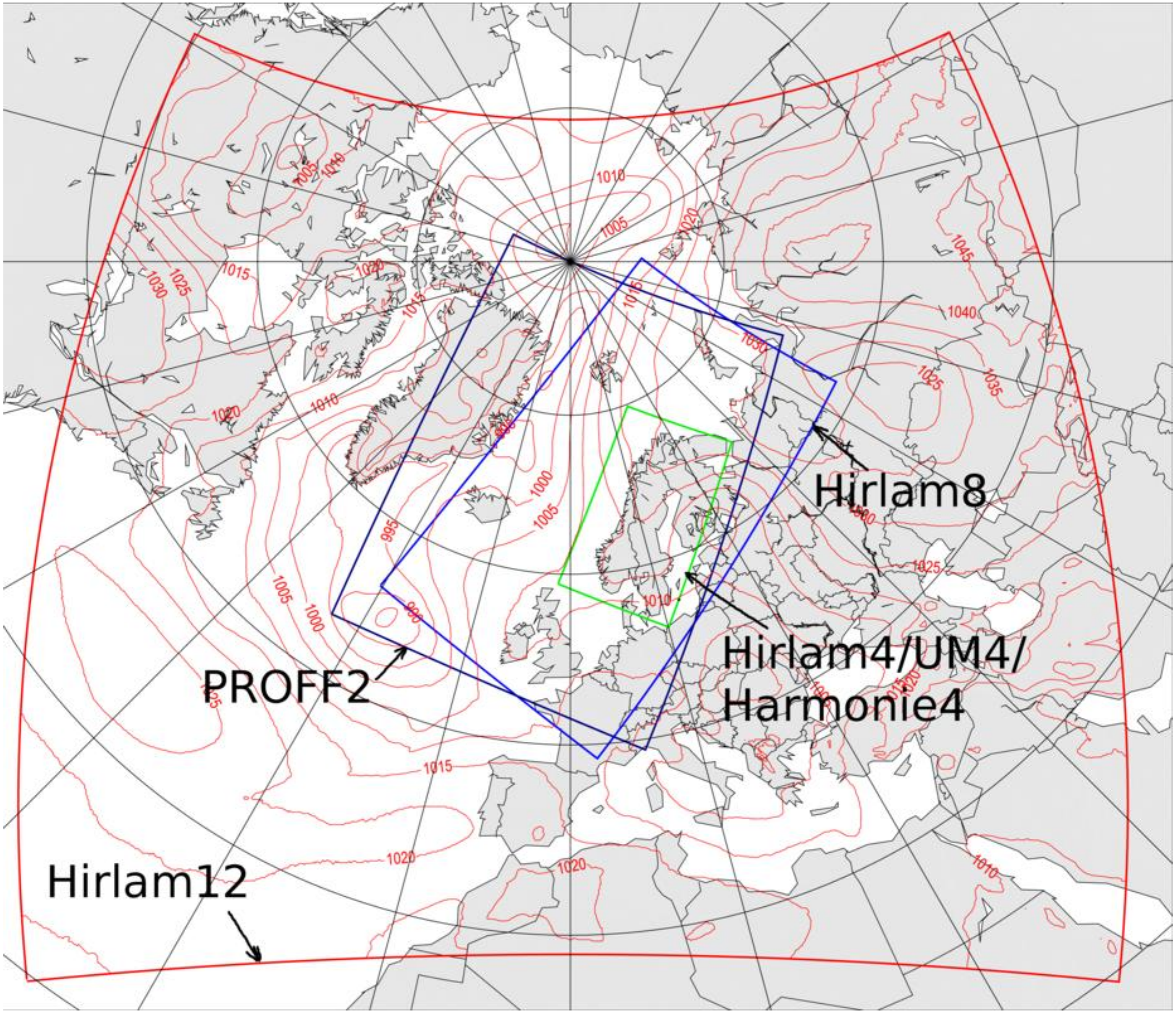
- Snow radiance modelling one of hardest microwave problems
  - Snow is a dense electromagnetic (EM) medium
  - Capturing layering is critical
  - EM signature highly sensitive to grain size (highly variable)

- Sparse in situ measurements
- Density can increase 2-50 kg/m3/day
- Ablation: ½ of Artic snowpack can ablate over a winter

Models:

- Input to DA: land surface models (LSMs)
- These could be off-line or coupled (e.g. atmosphere model)
- Examples of state-of-the-art models:
    - SURFEX (Météo-France, HIRLAM)
    - JULES (UK MetO)

NWP model domains: spatial resolution



Uncertainties in numerical modelling

(1) Model structure

- Parametrizations
- Putting model components together
- Numerical methods

(2) Model forcing

- Spatial & temporal structure

(3) Parameter data

- Soils & vegetation (type & distribution)

(4) Initial conditions

- Influences trajectory (cf. Forecasting)

Issues with snow in models

Results from work at Met.no and other groups in HIRLAM

- Strong sensitivity to snow in temperature forecasts from NWP models: negative bias in temperature when snow present

- Current snow models have snow on ground too long in melting season (e.g. in valleys)

- Need for more realistic snow schemes: design of parametrizations, incl. dependencies: e.g. fractional snow cover from snow water equivalent, SWE

Potential improvements

There are several snow schemes (e.g. associated with SURFEX model)

- Snow analysis
  - Tuning of OI (optimal interpolation) scheme
  - Observations from synop stations
  - Satellite data
  - More advanced analysis methods

- More realistic snow schemes
  - "Newsnow" in HIRLAM
  - Developed in SURFEX (HIRLAM) and JULES (UK MetO)

Snow assimilation:

- Role of assimilation (e.g. snow):
    - Initial state (forecasting)
    - Monitoring (e.g. elements of hydrological cycle)
    - Evaluation of observations/models

- Accurate prediction of snowpack status important for environmental applications, but model estimates typically poor & *in situ* measurement coverage inadequate
- Remote sensing estimates spatially & temporally limited due to complicating effects: incl. distance to open water, presence of wet snow & presence of thick snow
- DA of remote sensing estimates into a land surface model (LSM) can capitalize on the strengths of both approaches (model + observations)
- To achieve this, reliable estimates of uncertainty in both remotely sensed & model simulated quantities (SWE) critical

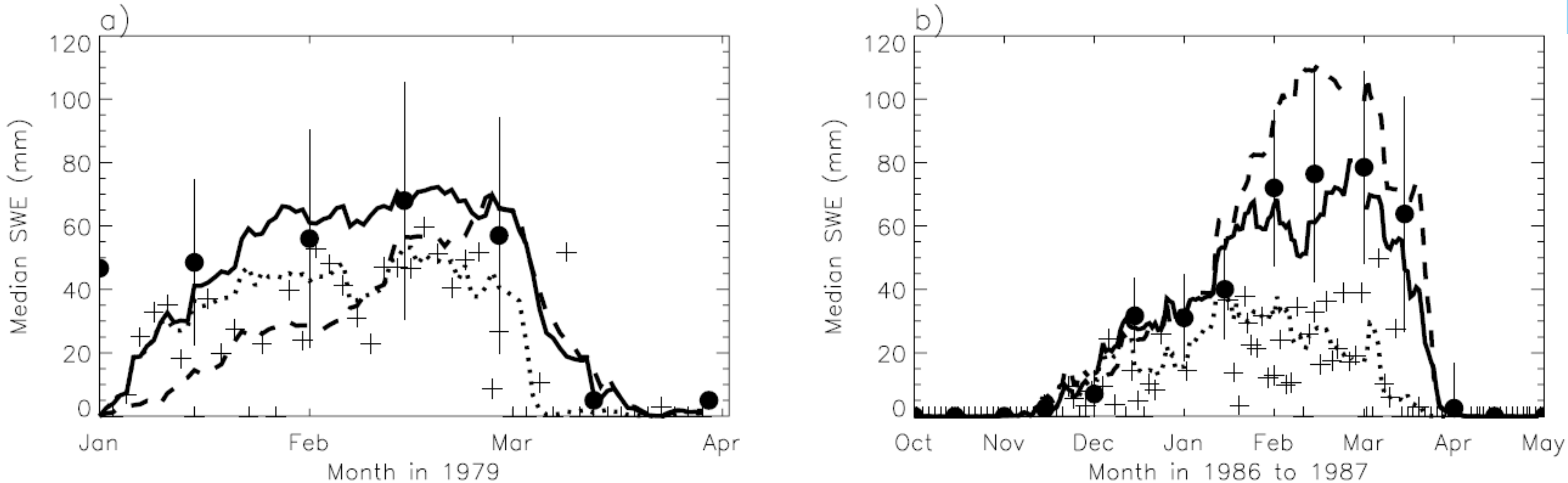
Snow quantities to assimilate

- Volume
  - Station SWE
  - Station depth
  - Station SWE/depth
- Area
  - Binary snow presence
  - Fractional unmixing
- Gravity anomaly


Photos : A. Slater

NSIDC

NIWA
Taihoro Nukurangi



DA Added value: Comparison of the median SWE for pixels including 5 or more stations; ground observations (black dots), SMMR observations (+ symbols), model forecast (dash lines), model forecast with DA run-I (dotted lines) and run-II (solid lines) from: a) Jan-Mar 1979 (left panel), and b) Jul 1986 - Jun 1987 (zoomed to winter months from Oct 1986 to Apr 1987 – right panel). Vertical lines show plus one & minus one standard deviation from median of ground observations.

Run-I: Assimilate all SMMR observations; Run-II: Assimilate QC SSMR observations

Houser *et al.*, 2010, *Land Surface Data Assimilation*, in "Data Assimilation: Making Sense of Observations", Springer, Eds. Lahoz, Khattatov, Ménard.

Applications of assimilation of hydrological quantities

- Hydrology: fluxes, volume forecast, flood forecasting, reservoir operations, water allocation

- NWP: Initial state, short-term predictions, better use of EO data, improved models

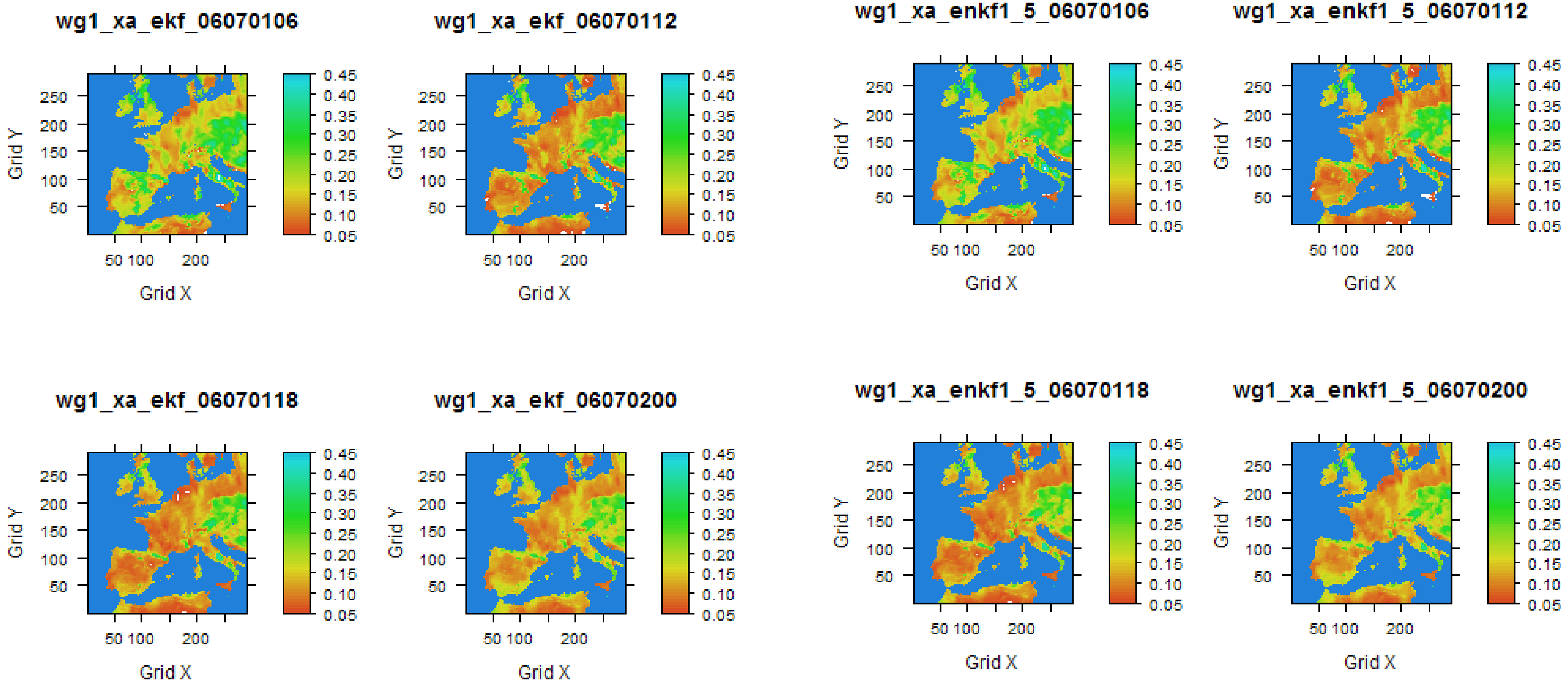
- Climate: Initial state, medium/seasonal predictions, improved models

- NWP/climate parameters: albedo, energy sink, soil moisture, soil insulation

GlobSNOW contribution:

- GlobSNOW contribution (SWE, SE)
- Observations (network) & access
- Resolution: spatial/temporal? (Houser et al. 2010)
- Discussion between observations/modelling communities
- Way forward: information exchange (multi-disciplinary approach)
- Build on land data assimilation work (e.g. Météo-France, Met.no, NILU, HIRLAM; ISSI International Team) with SURFEX and state-of-the-art land DA algorithms – special features of land DA (non-Gaussianity, non-linearity)

Lahoz et al., 2010, The NILU SURFEX-EnKF land data assimilation system. NILU publication, January 2010.



Superficial volumetric water content (m^3/m^3), analysed 4 times, 0006, 1200, 1800, 2400 UTC

1 July 2006; left EKF; right square root EnKF (mean of 5 ensemble members)

Strategic issues (from the standpoint of Arctic Land Hydrology) – from Paul Houser

• What processes are most critical, and how can observational base best be improved?

• ***Rivers*** – major rivers reasonably well gauged (notwithstanding budget pressures & complications of estimating discharge during ice breakup, etc) – however "interior" gauge network sparse & under continuing pressure, generally number of Arctic gauges has declined over land ~20 years. Possible role of swath altimetry (complications include ice cover, overpass interval)

• *Snow on ground* – some *in situ* measurements, but vast area – remote sensing offers promise, & some success already with passive microwave sensors (most algorithms use 19/37 GHz channels). Complications include mixed pixels (esp. forest), & topography, among others.

• ***Evapotranspiration*** – usually by difference, possibility for indirect inference and measurement of key variables (Ts, vegetation indicators) via remote sensing

• ***Precipitation*** – role of GPM (Global Precipitation Measurement)? Sampling issues? Strategies for data assimilation?

• Need to move towards ***advanced process models***, assimilation methods, and validation.

• Need to move ***toward integrated science assessments*** (i.e. putting the water cycle pieces together), & interdisciplinary big-picture teamwork

-> Role for GlobSNOW: observational database; interaction with models, Land DA