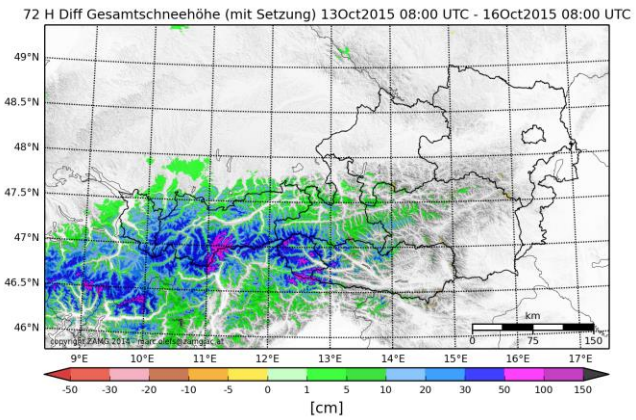
SNOWGRID Workshop

SNOWGRID – Distributed operational snow cover modeling



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Zentralanstalt für Meteorologie und Geodynamik

M. Olefs, H. Bamberger, A. Kann, C. Wittmann, F. Meier, F. Weidle, J. Haslhofer, B. Niedermoser, A. Neururer, A. Studeregger, A. Beck, C. Zingerle
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SNOWGRID: outline

1. Motivation
2. Methods and Technical Stuff
3. Validation (Analysis/Forecast)
4. Dissemination
5. Coupling to NWP Models at ZAMG
6. Conclusions and outlook

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Motivation

Motivation for operational snow cover modeling

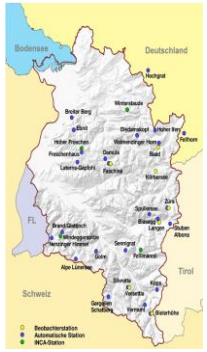
Situation until 2013

- Insufficient informations about spatial distribution of seasonal snow in AT
  (in-situ point measurements e.g. AWS, HS, HPC,…)
  Satellite (no reliable quantitative information in Alps and only during clear-sky)
- Need for a spatially distributed snow cover model over entire AT

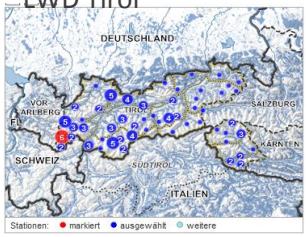
point measurements…

LWD Bayern

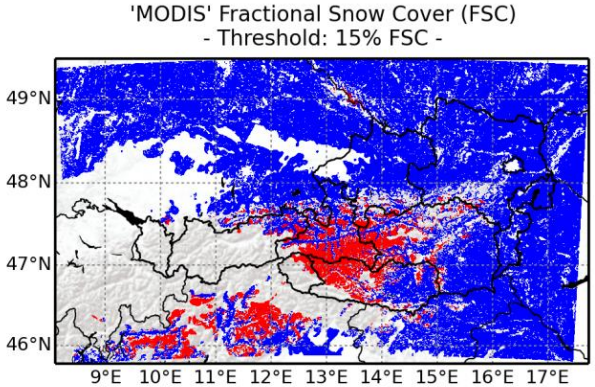
LWD Vorarlberg



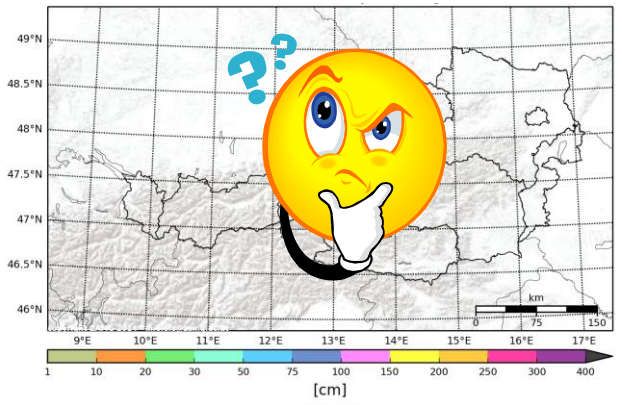
LWD Tirol

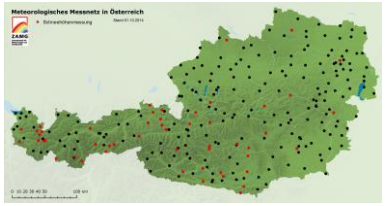


Sat data…

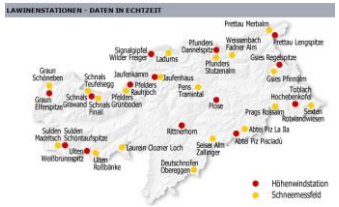


The spatial distribution of snow…





LWD Autonome Provinz Bozen - Südtirol



Simple snow models can help combining the best of both worlds!

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SNOWGRID: Motivation / Demand (user perspective)

Snow load & infrastructure

(winter) road management

Hydrology

(runoff, flood, hydro power)

Avalanche warning

Wintertourism

Power grid

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Methods
&
Technical stuff

SNOWGRID: Methods & Technical stuff

- Operational spatially distributed snow cover model with high spatial (100 m) and temporal (15 Minuten) resolution for INCA-L grid (Zürich-Bratislava, Nürnberg-Triest ~ 28 m gridpoints)
- Near realtime (Analysis), Reanalysis (back to Jan 2006) und forecast (ALARO/ECMWF up to +72 h)
- Upper BC: Meteo. Input from INCA. Lower BC: INCA ground temps
- Simple degree-day scheme (operational) and more complex energy balance mode (experimental), simple 2-layer snow model (swe-driven, considering e.g. time-variable heat content, snowline depression, settling), state variables are: swe, snow depth, average snow temp, liquid water content
- Topography: 100 m DEM (corrected NASA SRTM3 + add. Data)
- Calibration/Validation: >50 in-situ snow depth ground stations (ZAMG/AWS), 5 swe
  > 200 manual swe/snow depth meas. (since 2011), MODIS FSCA, data from HS,…
- Output grids: snow depth, SWE, average snow temp (+new snow in forecast mode)
- Current use of satellite data: spatial validation only (no assimilation)

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SNOWGRID: Methods & technical stuff

Degree-day mode (currently operational):

- Topography: 100x100 m DEM, Slope (snow cover settling), crest height & sky view factor (snowline depression effect)

- Meteorology:
  - Analysis mode: INCA air temperature, rel. humidity, snowline (wet-bulb temp.), precipitation, snow cover ablation using air temperature & degree-day factor (seasonal variation)
  - Forecast mode: „INCA_OPT“ precipitation (weighted ALARO/ECMWF data), T2Mc (ALARO bias-corrected), RH2m (ALARO), ZS (ALARO)
  - Simple bilinear interpolation to 100 m

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SNOWGRID: Methods & technical stuff

- simple 2 layer model
- Calculation of time variant heat content of snow cover (snow vs. air temperature), considering energetic effect of liquid precipitation on snow
- Snowline depression effect = f(initial snowline, crest height, precipitation, DEM)
- State variables are: snow depth, SWE, average snow temperature
- Fresh snow density = F(air temperature)
- Snow settling (rapid setting after snowfall - destructive metamorphism, density-dependant slower settling thereafter (overburden pressure, metamorphism)
- Fresh snow temperature = wet-bulb temperature of the air during snowfall

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SNOWGRID: differences to more complex snow models

Whats the difference between SNOWGRID and SNOWPACK, SNTHERM, CROCUS,…??

SNOWGRID…
…only has 1-2 layers

…does not consider the snow microstructure

…does not calculate any vertical temperature or water profiles

…no differential equations to solve

…is **extremly** faster

…28 m gridpoints in < 1 Minute per timestep (degree-day version)

…in point mode: > 200 points entire winter season < 1 minute

…easily extendable (written in Python)

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SNOWGRID Validation (Analysis)

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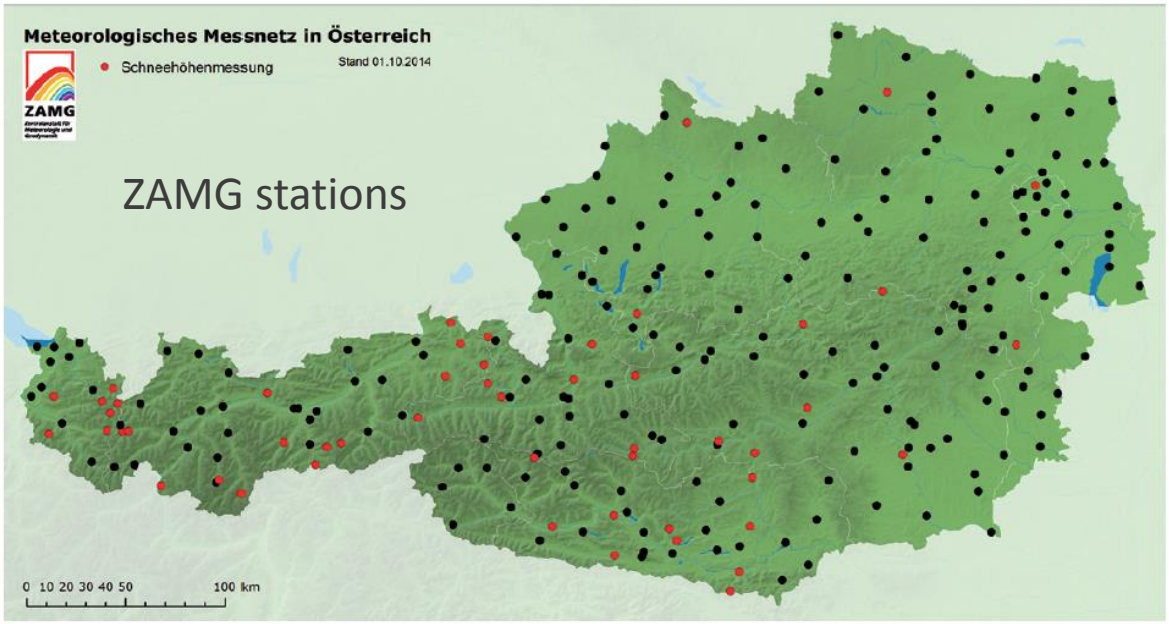
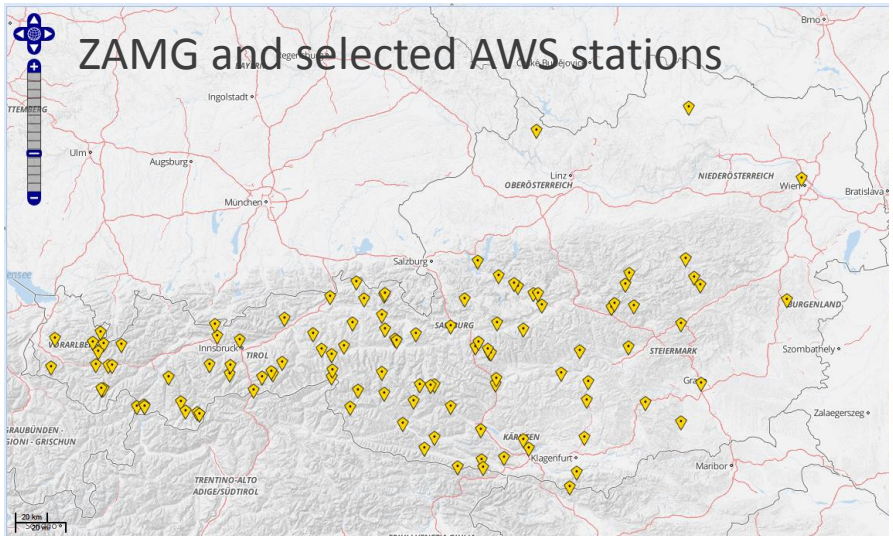
SNOWGRID: Point validation data

Automatic station network ZAMG (~250 meteo stations in total).

63 ZAMG snow stations (snow depth using laser sensor)

59 seletcted stations of regional Avalanche Warning Services





Gerald Lang, Marc Olefs, Martin Mair

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SNOWGRID: Validation (point measurements, spatial (MODIS))

Manual snow measurements SD, SWE, changing locations (n=212, 3 seasons (2011-2014))

- ✓ SWE: MAE = 106 mm, BIAS= 28 mm
- ✓ SD: MAE = 0.54 m, BIAS= 0.5 m

autom. Snow depth meas. (Laser, ZAMG/AWS) (n> 50 / Season, 3 Seasons (2011-2014))

- ✓ r^2 = 0.73, BIAS = 0.16 m

MODIS fractional snow cover (250 m, daily) (Cloudiness < 50 % in model domain, 2 seasons (13/14, 14/15), n=118 Days)

- ✓ KSS = 0.77, HR= 0.93, FARsnow = 0.21

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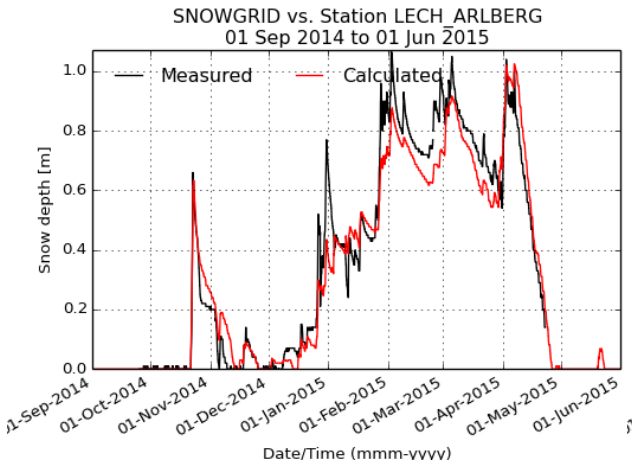
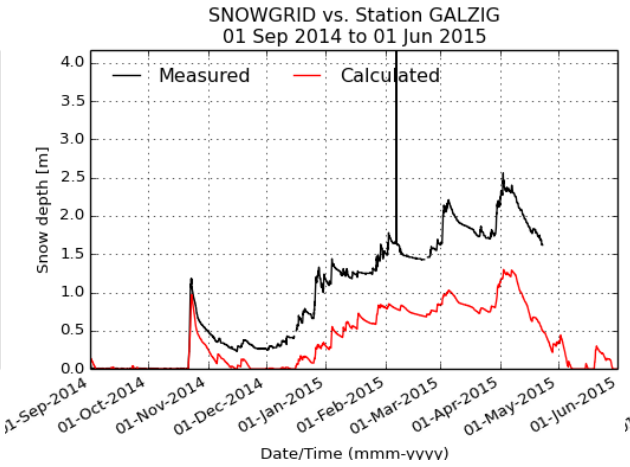
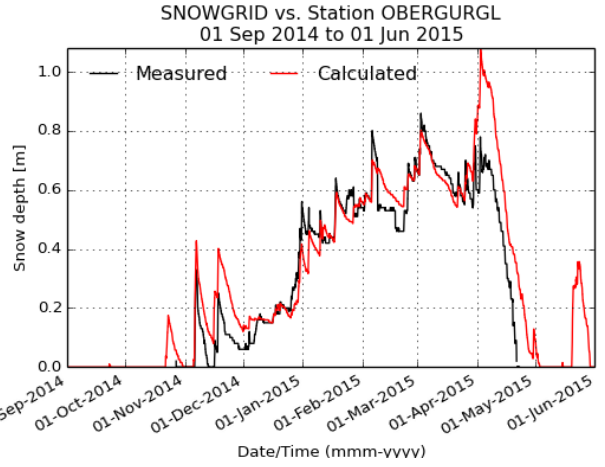
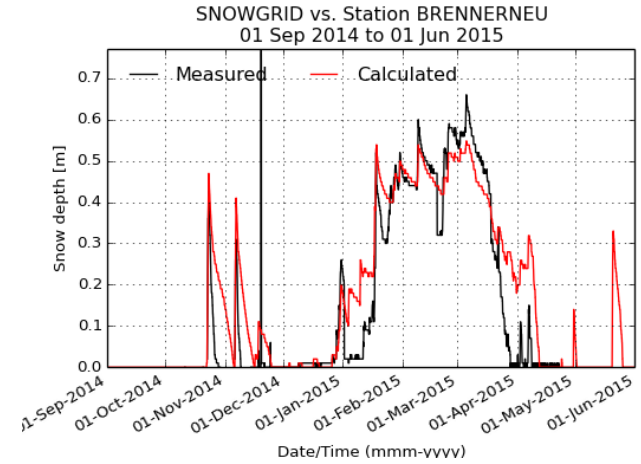
SNOWGRID: point validation (snow depth time-series)

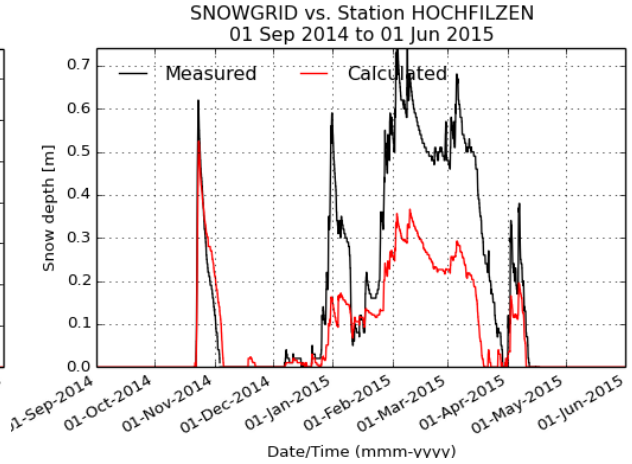
Winter 2014/15

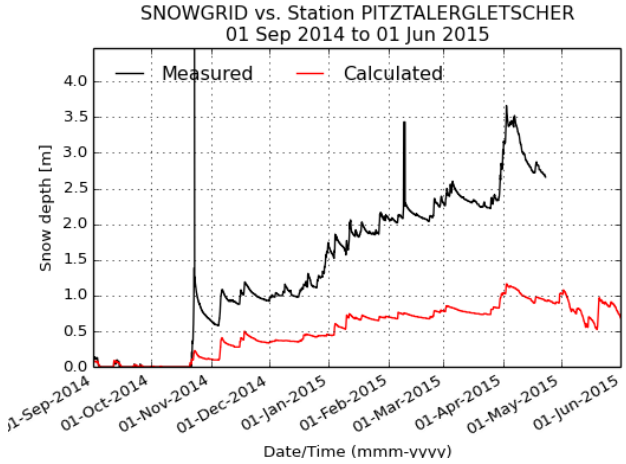












Good timing and detection of individual snowfall events
But also larger under-/overestimations of single events that propagate in time

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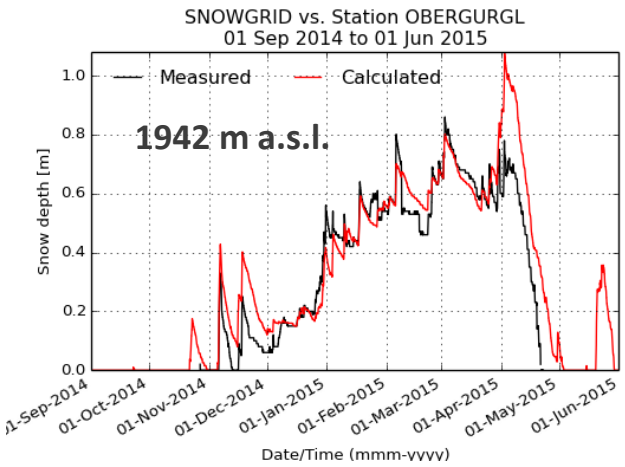
SNOWGRID: Typical problems

Example: Undercatch of winter precipitation: TAWES -> INCA -> SNOWGRID
SNOWGRID is SWE-driven -> too much /less precipitation input means over-/underestimation of SWE and SD



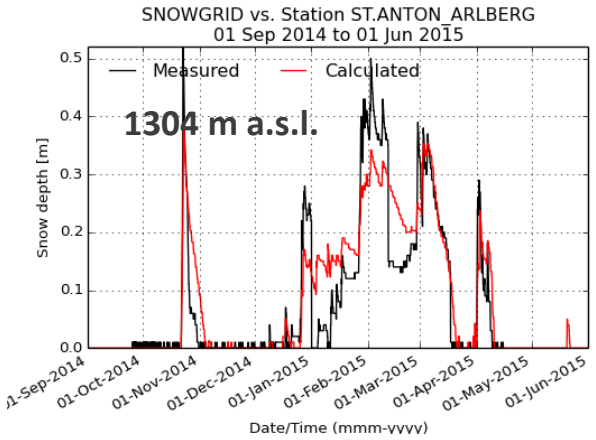
Winter 2014/15

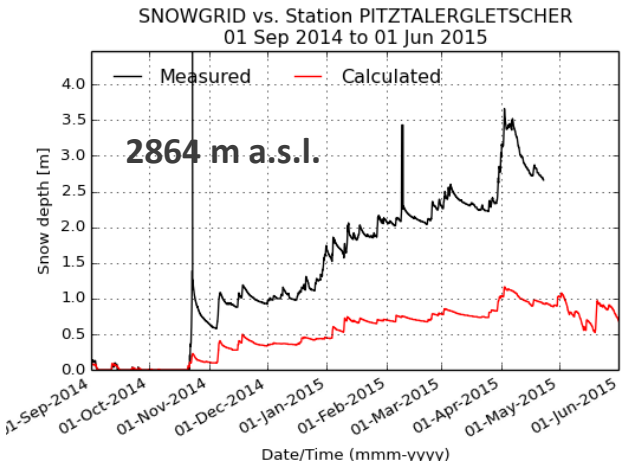
(wind-) sheltered station

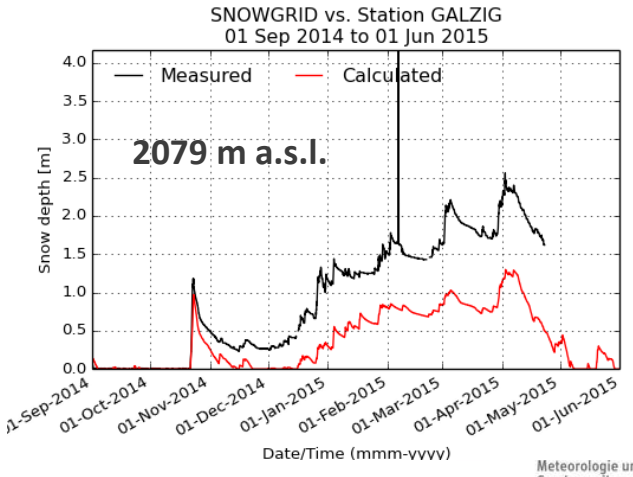
horizontal distance

13 km ↕ 3 km

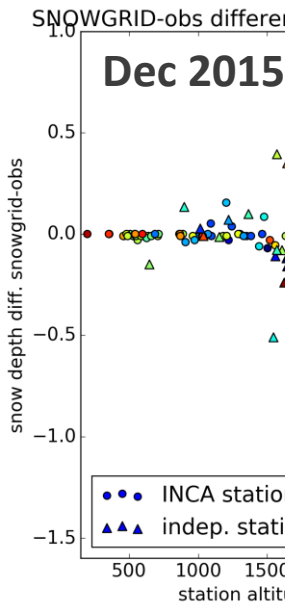
(wind-) exposed station

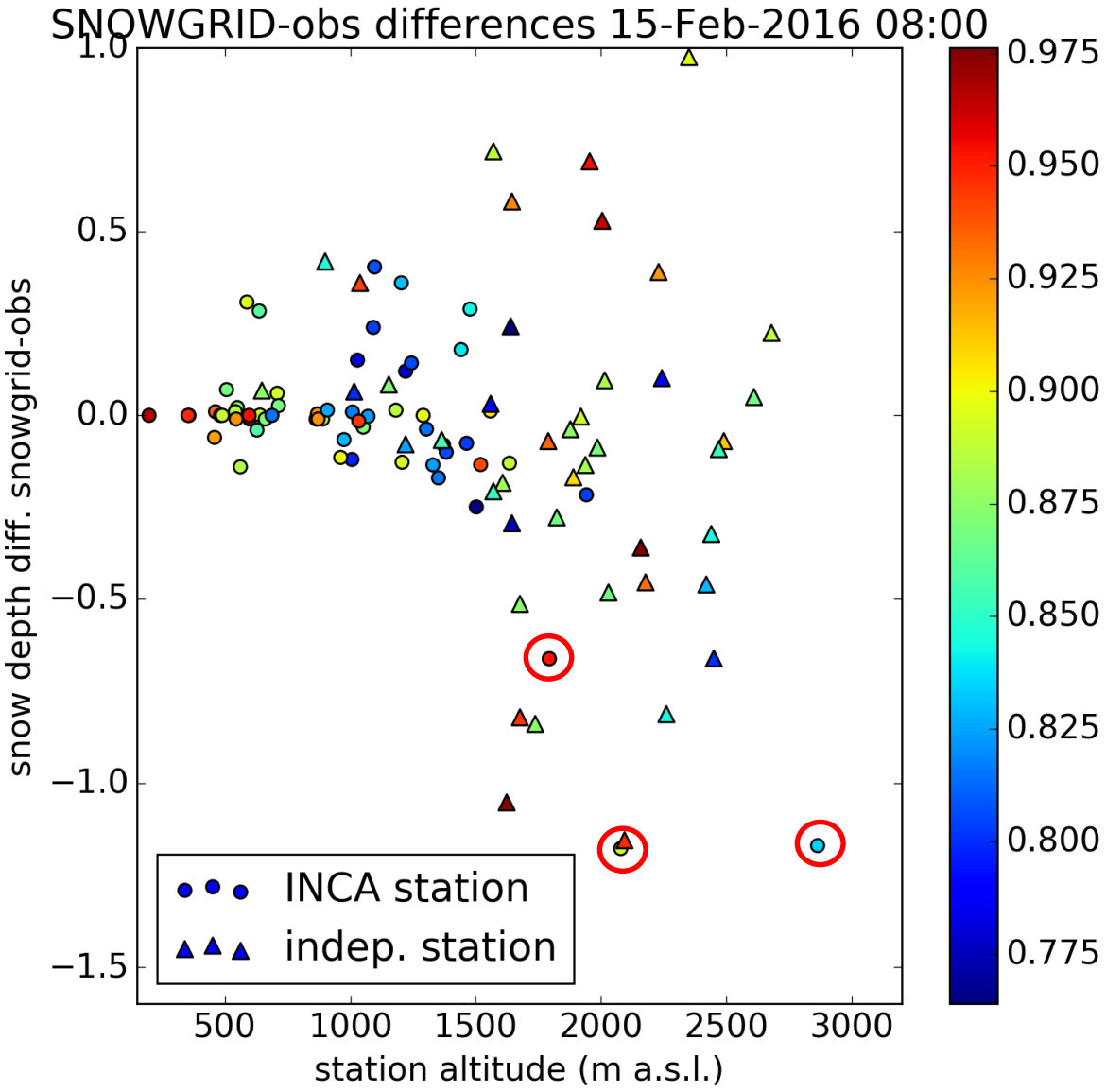


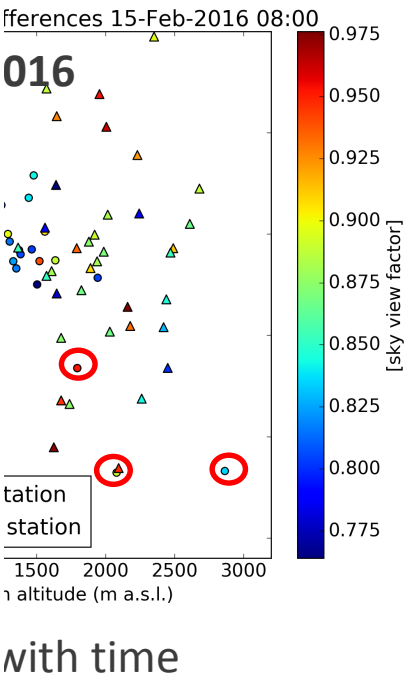




SNOWGRID: Towards assimilation of point observation







with time

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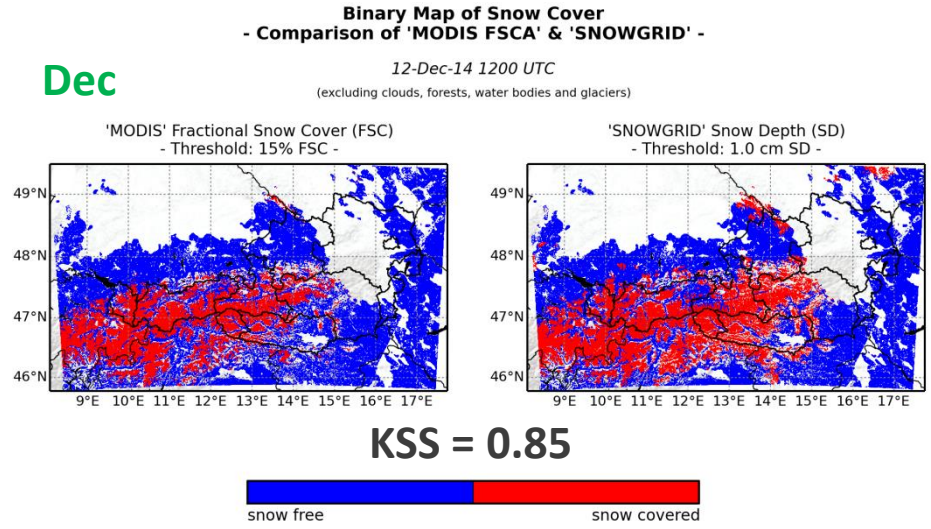
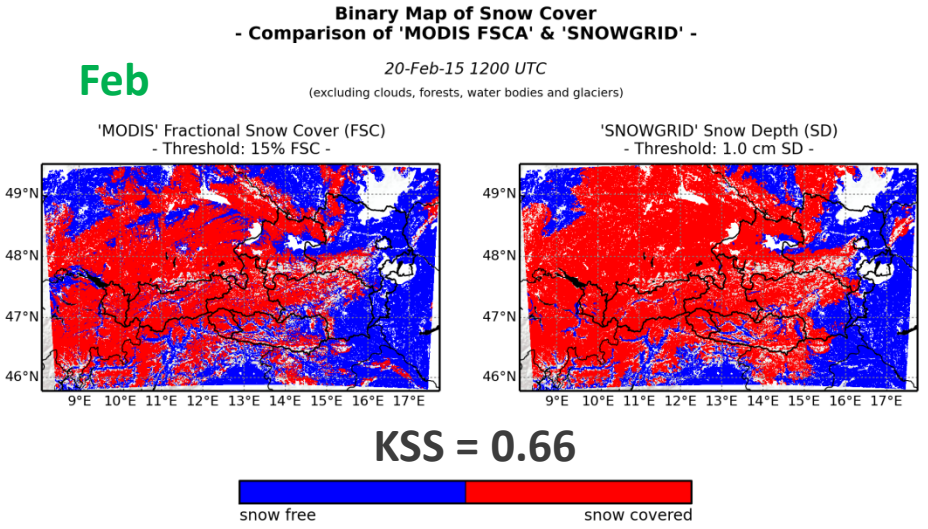
SNOWGRID: spatial validation MODIS: 2014/15

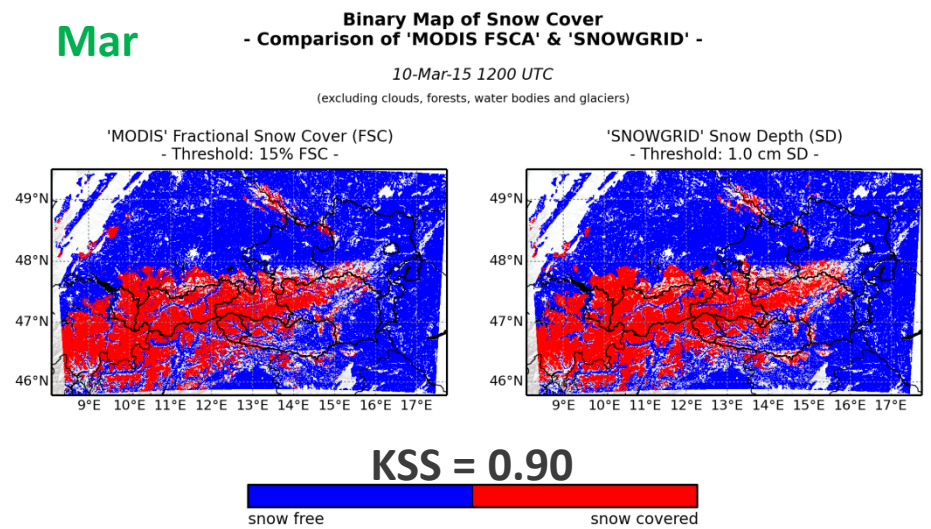
Dec



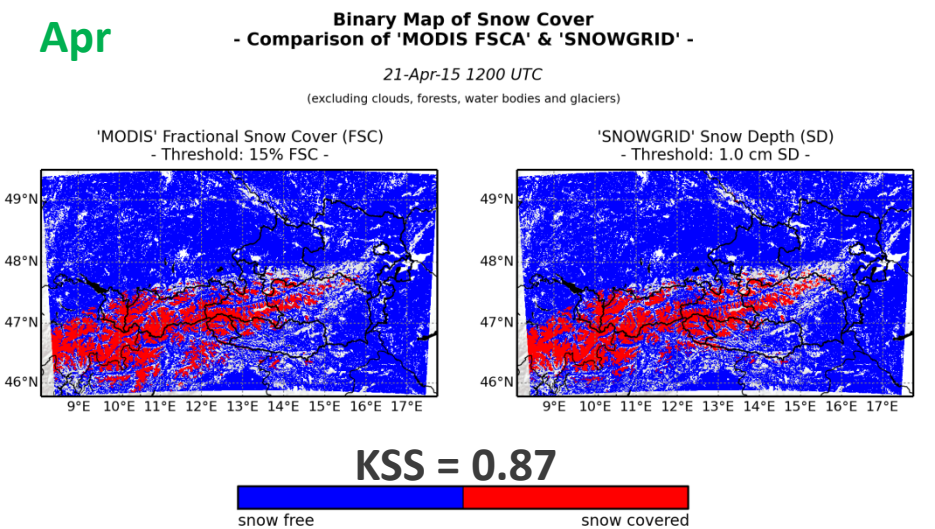
Feb



Mar



Apr



Average over 51 days (2014/15) : Skill score = 0.78 (1 = best)

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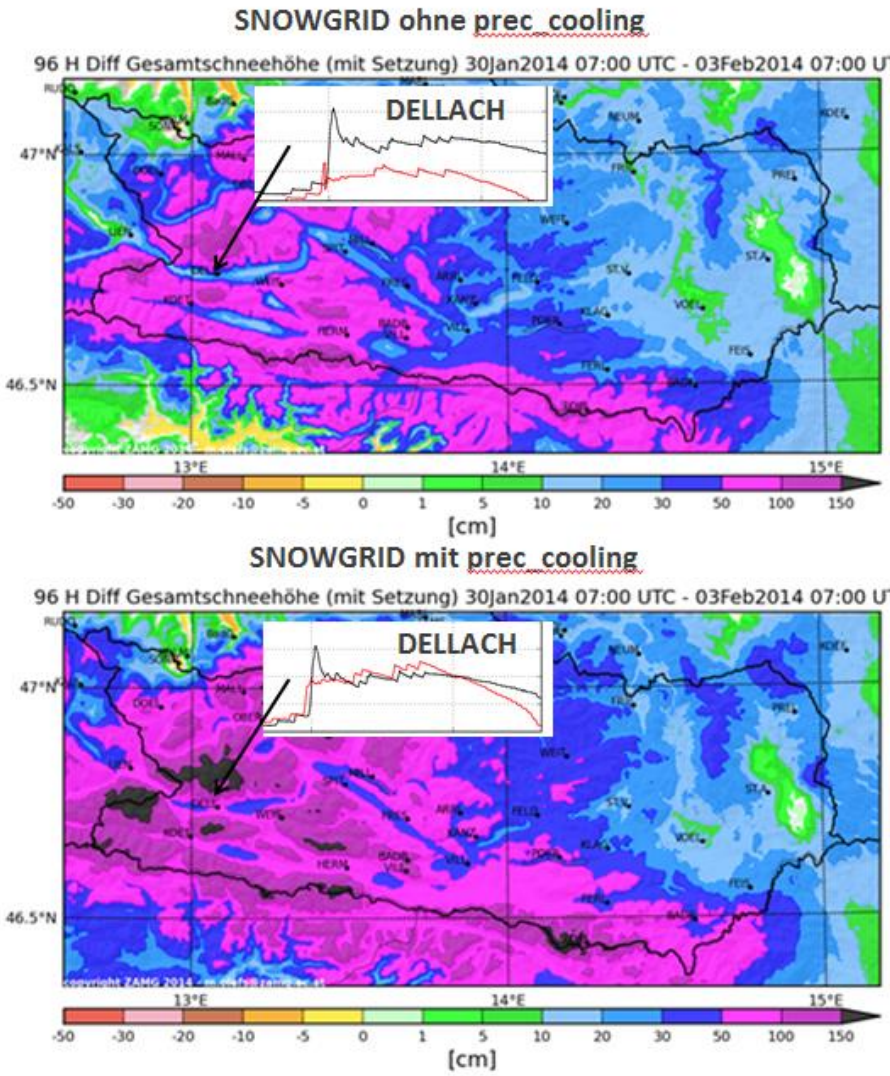
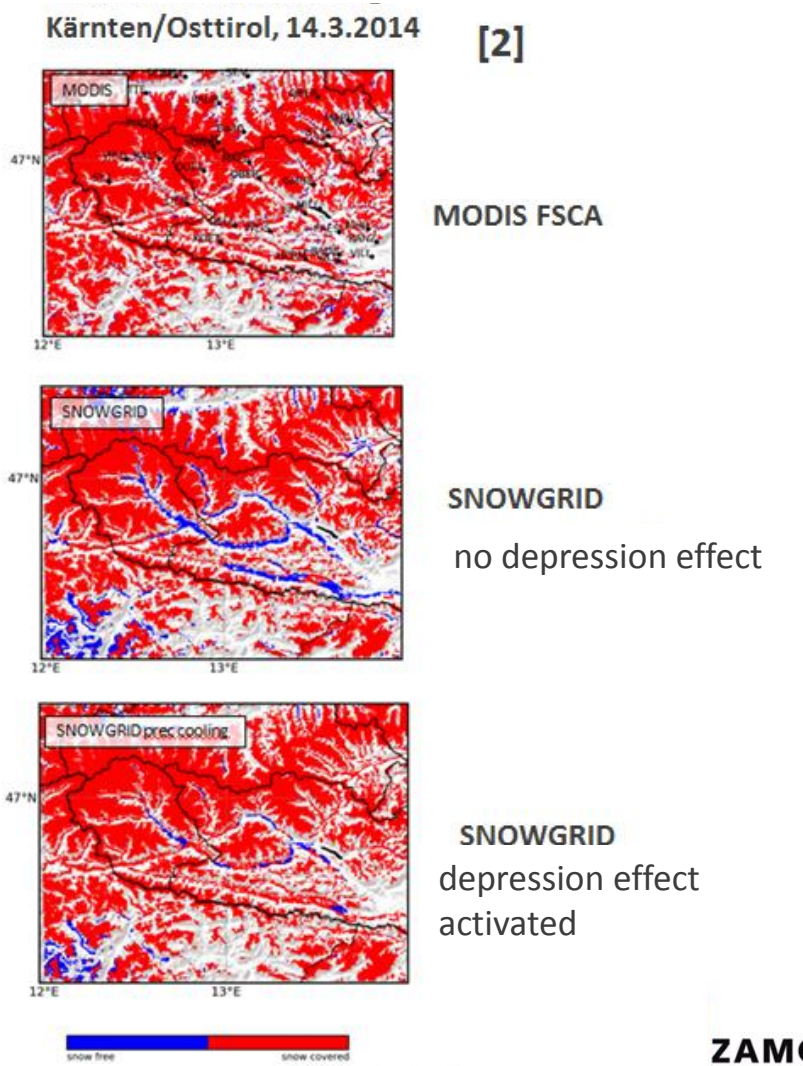
SNOWGRID: Validation of snowline depression effect



binary snow cover



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SNOWGRID validation (forecast)

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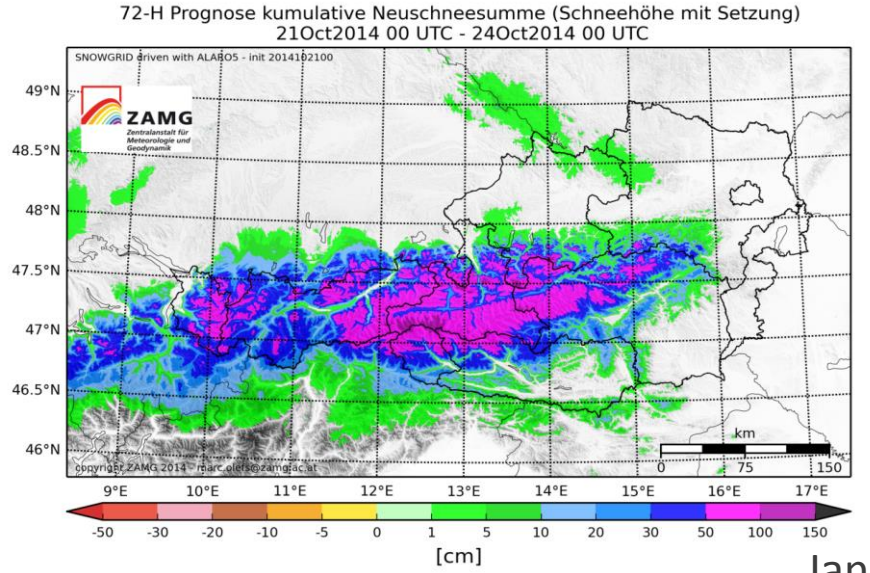
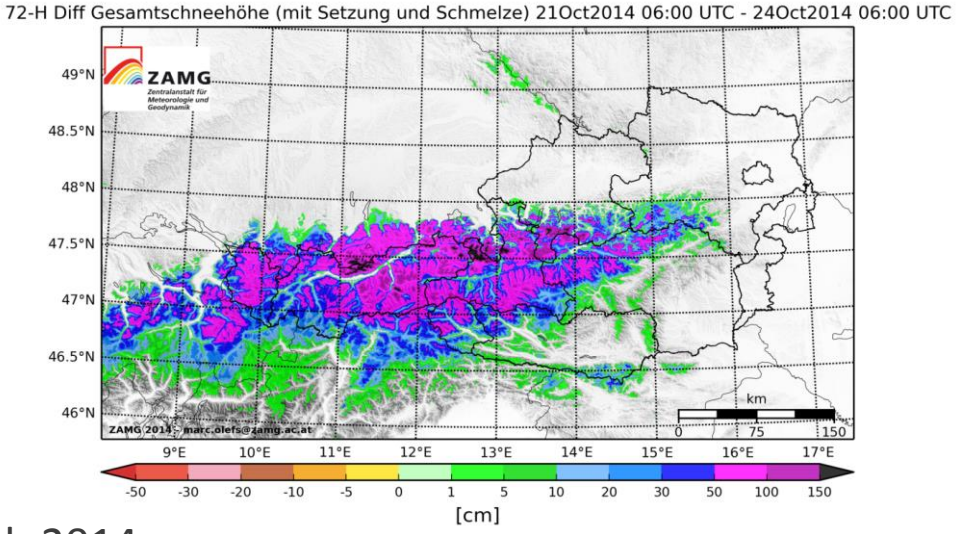
SNOWGRID: forecast validation

Forecast

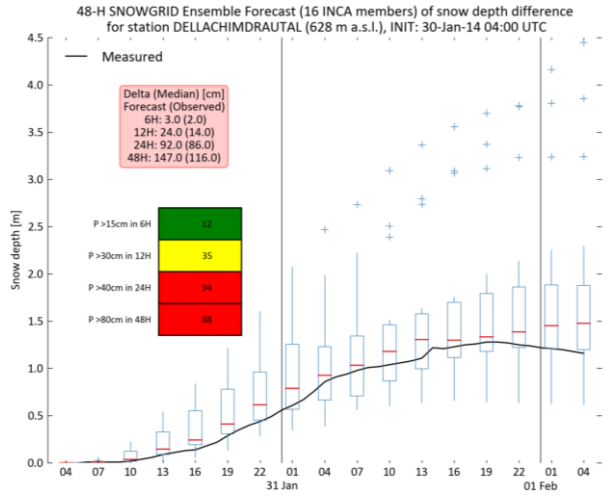
Oct 2014

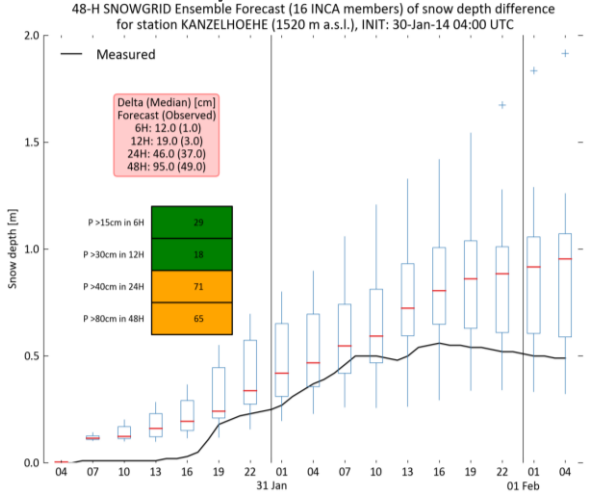
Analysis

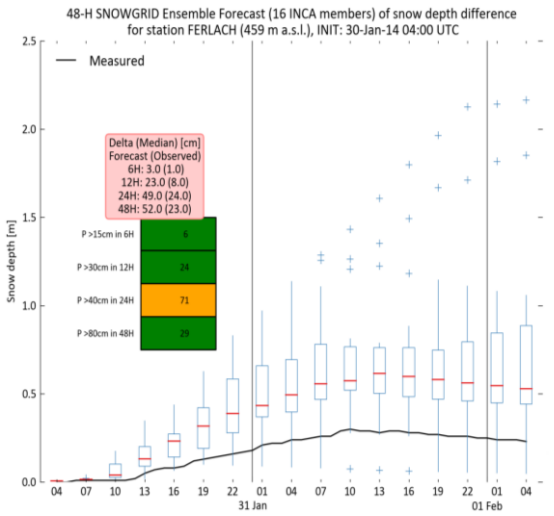




Jan/Feb 2014

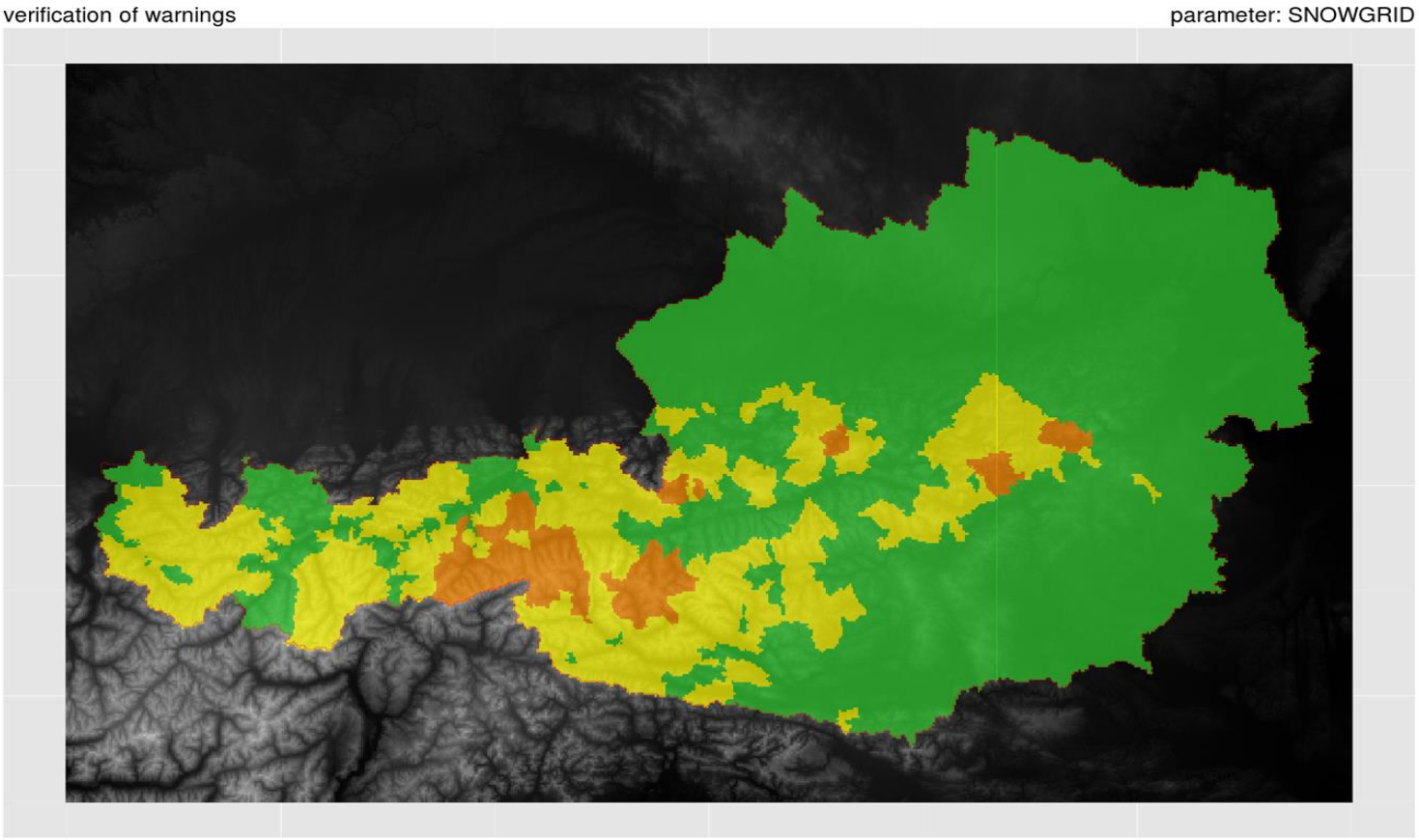






SNOWGRID: Validation of snow warnings

Fresh snow warnings based on forecasted cumulative fresh snow sums and tresholds (on municipality level; 4 warn levels)



„percentage correct“ of snow warnings based on 24-H forecasts (twice a day) for 18 Feb-11 Apr 2016

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SNOWGRID
Dissemination

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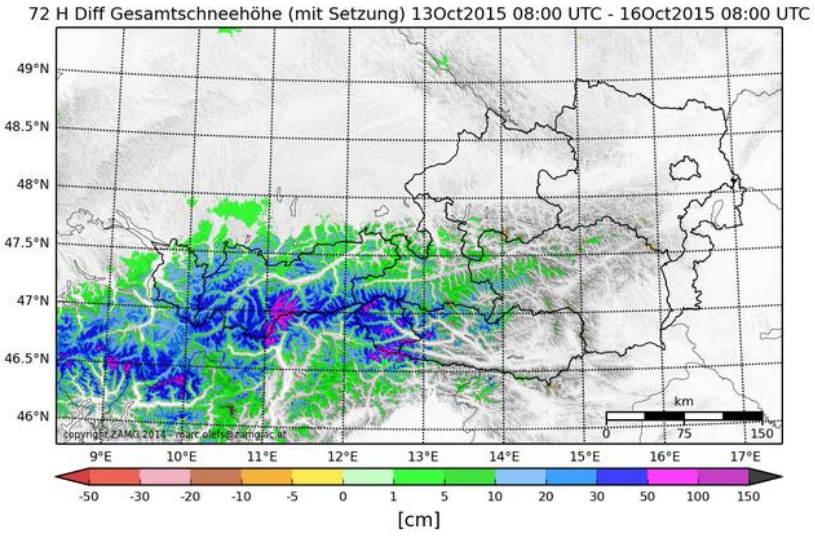
SNOWGRID: internal visualization tools

Static (PNGs): only actual data

	Österreich	Vorarlberg u Tirol	Salzburg	Oberösterreich	Steiermark	Kärnten	NÖ & Wien	Burgenland
ANALYSE	SHGT SWE	SHGT SWE	SHGT SWE	SHGT SWE	SHGT SWE	SHGT SWE	SHGT SWE	SHGT SWE
DIFF SHGT	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72
DIFF SWE	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72	-6 -12 -24 -48 -72
PROGNOSE SHGT (cum)	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72
PROGNOSE SWE (cum)	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72	+6 +12 +24 +48 +72
PROGNOSE SHGT/SWE	SHGT +72 SWE +72	SHGT +72 SWE +72	SHGT +72 SWE +72	SHGT +72 SWE +72	SHGT +72 SWE +72	SHGT +72 SWE +72	SHGT +72 SWE +72	SHGT +72 SWE +72



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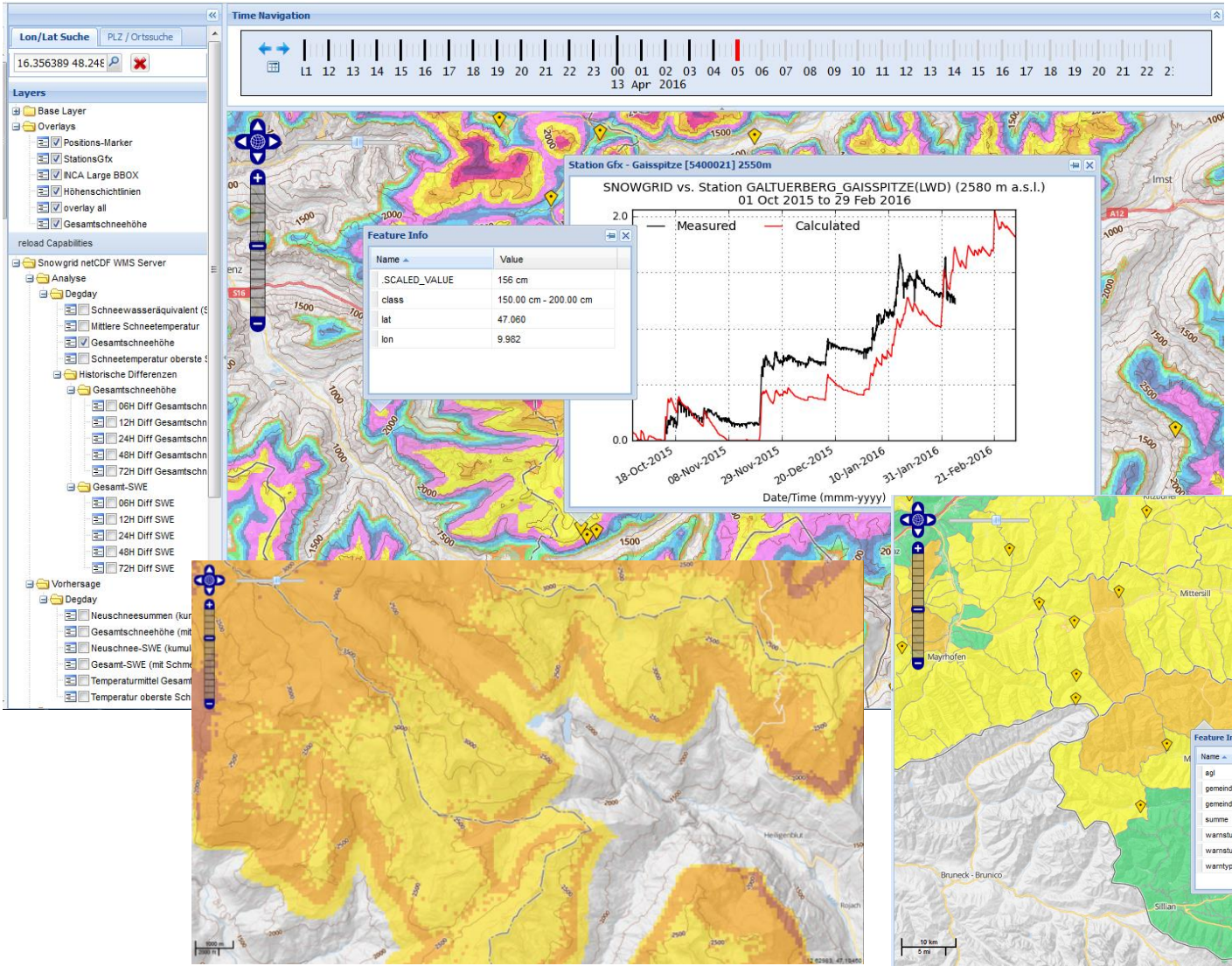
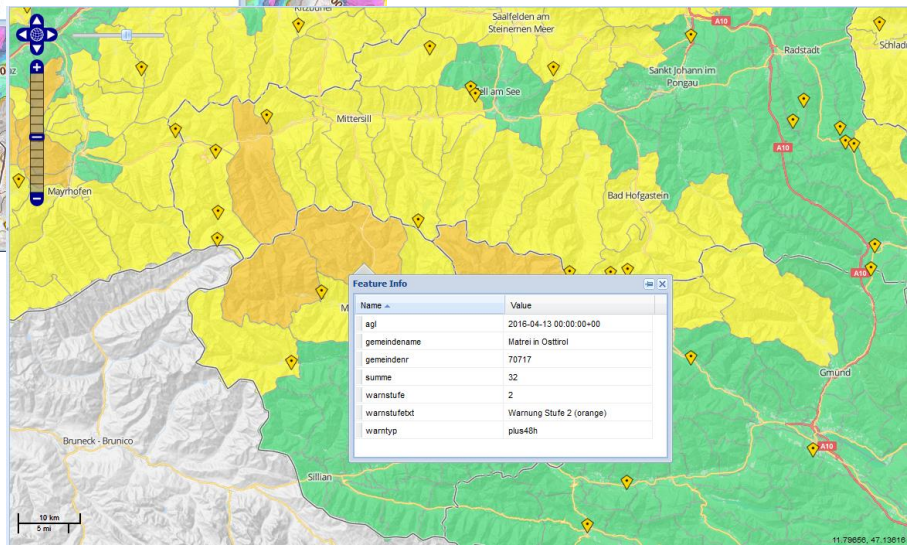
SNOWGRID: internal visualization tools

Web Map Service: actual data and archive

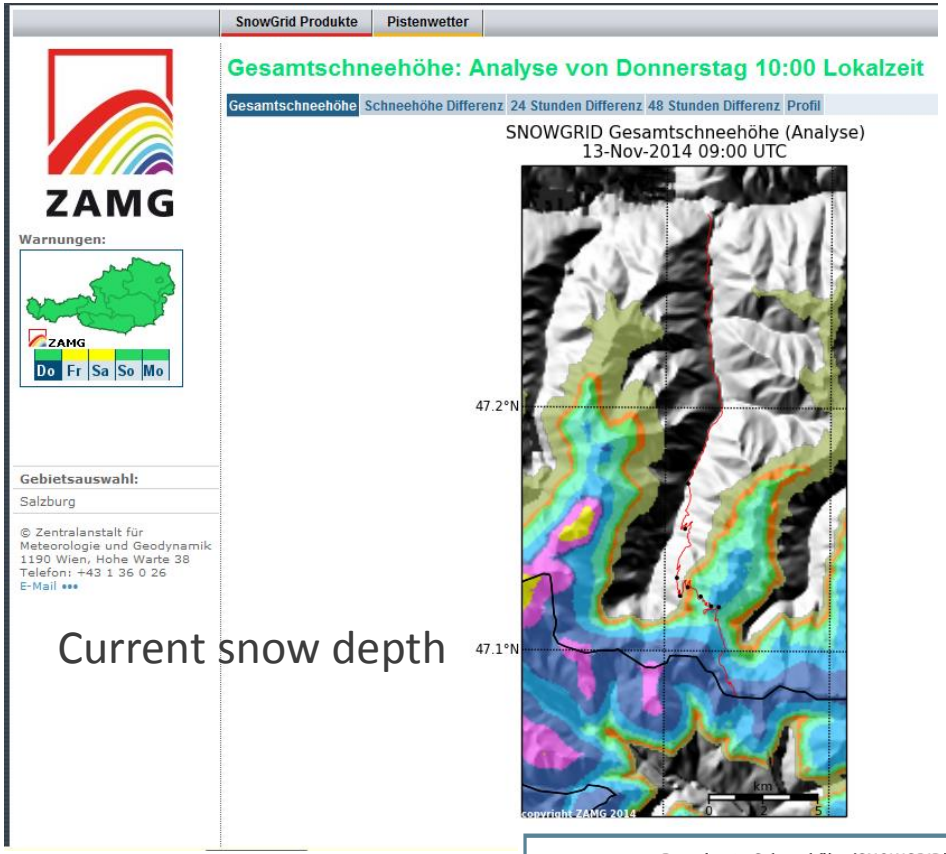




analysis and forecasts
snow warnings
Comparison with
point measurements
(near realtime)
Feature point requests

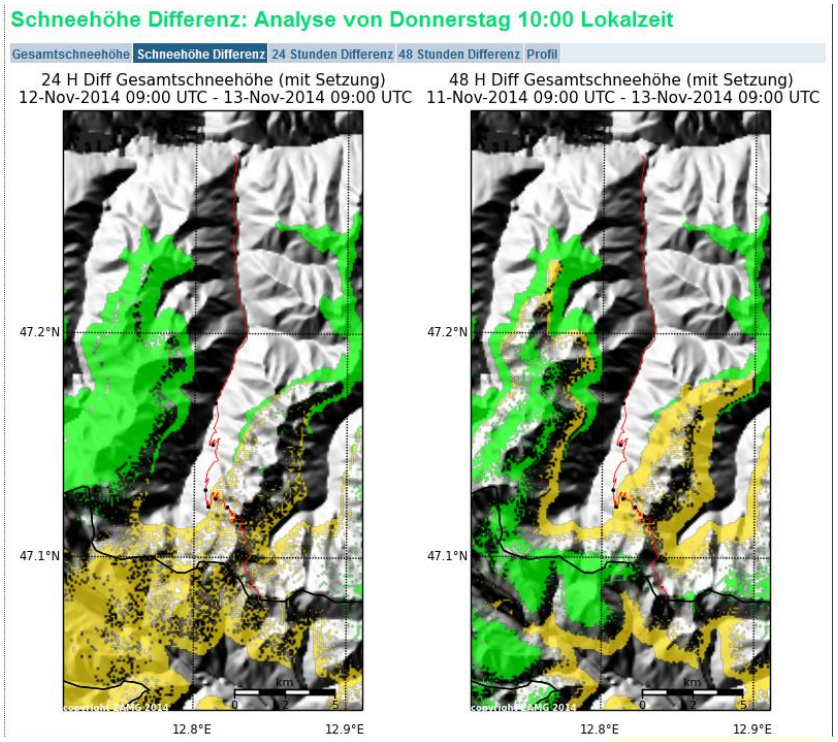
SNOWGRID: costumer product example I

Operational (high alpine) road weather product (GROHAG)

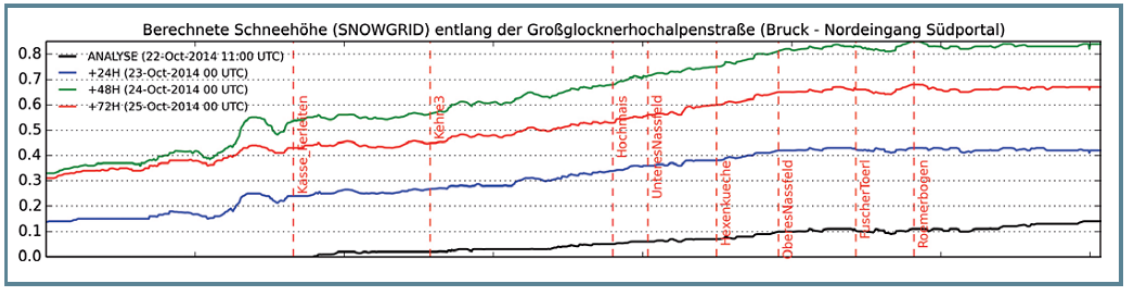


Current snow depth

Historical snow depth differences



Analysis & forecast of snow depth along The road



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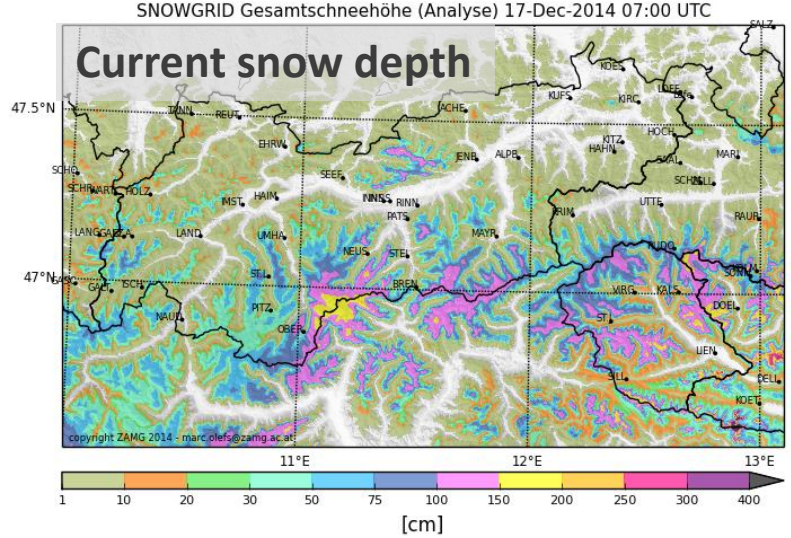
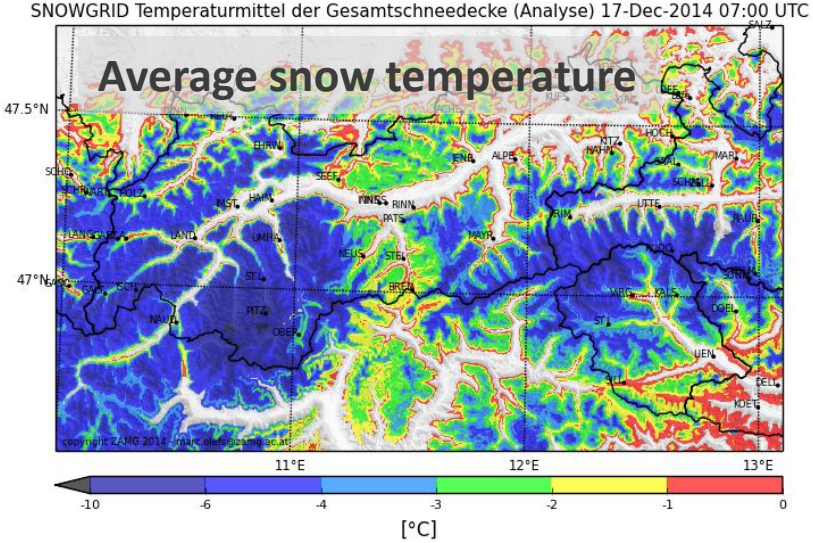
SNOWGRID: costumer product example II

Avalanche warning service Tyrol

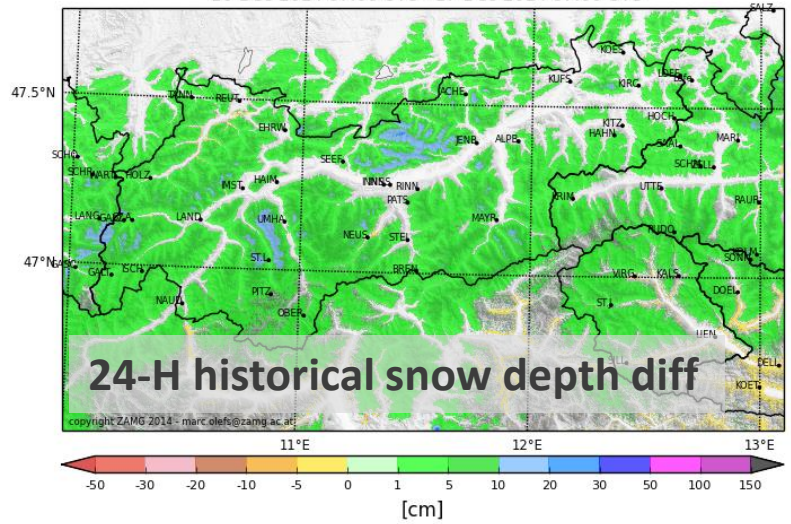
SNOWGRID Gesamtschneehöhe (Analyse) 17-Dec-2014 07:00 UTC



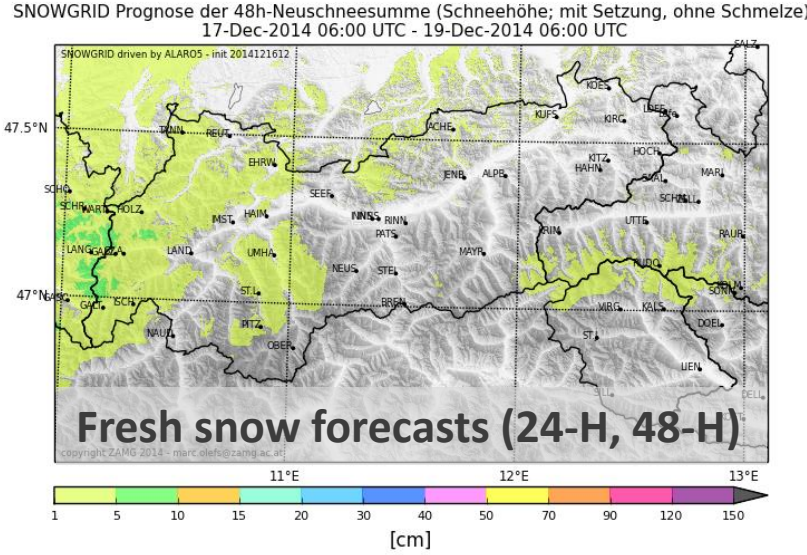
SNOWGRID Temperaturmittel der Gesamtschneedecke (Analyse) 17-Dec-2014 07:00 UTC



SNOWGRID 24h-Differenz der Gesamtschneehöhe (mit Setzung und Schmelze)
16-Dec-2014 07:00 UTC - 17-Dec-2014 07:00 UTC

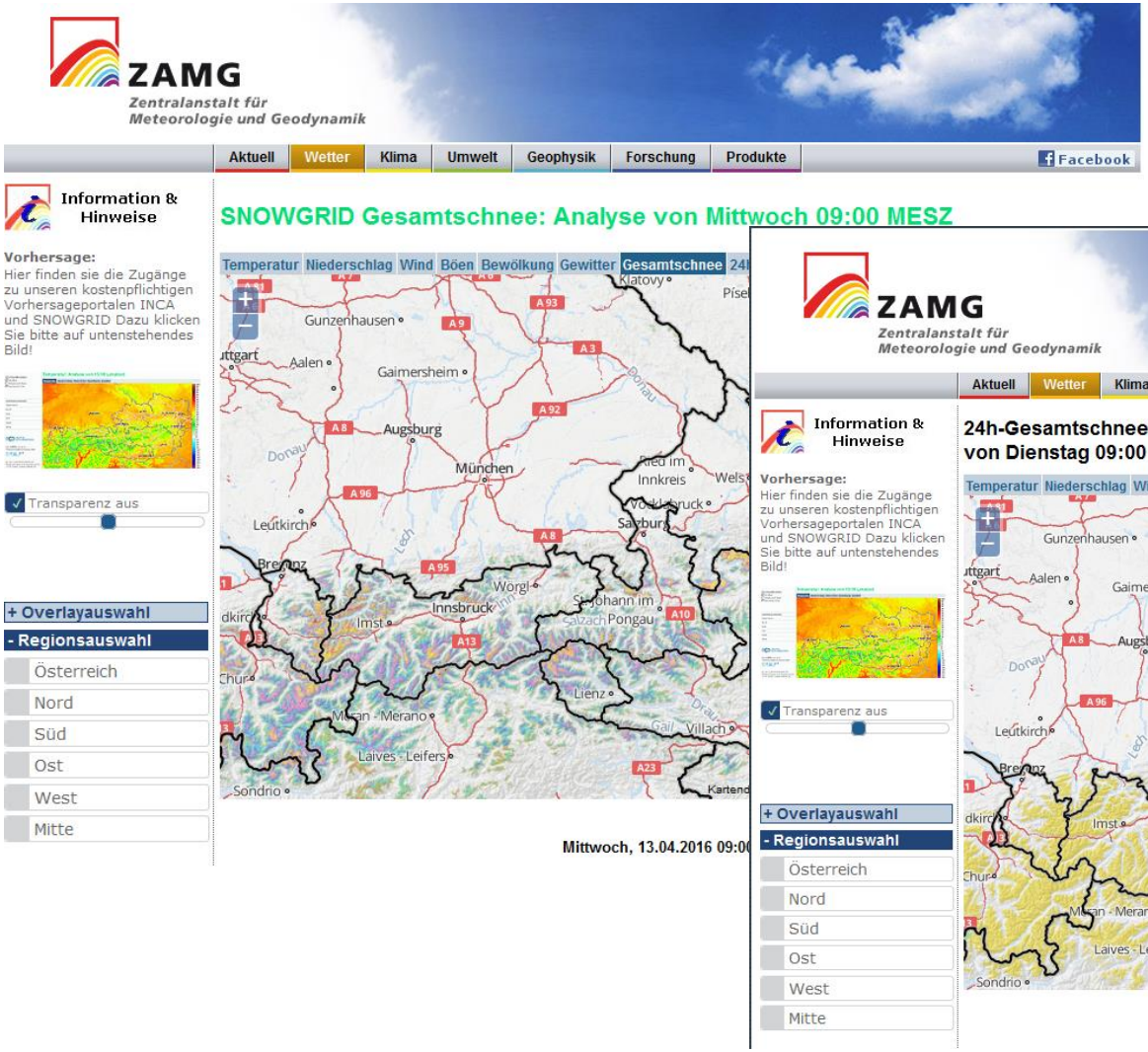


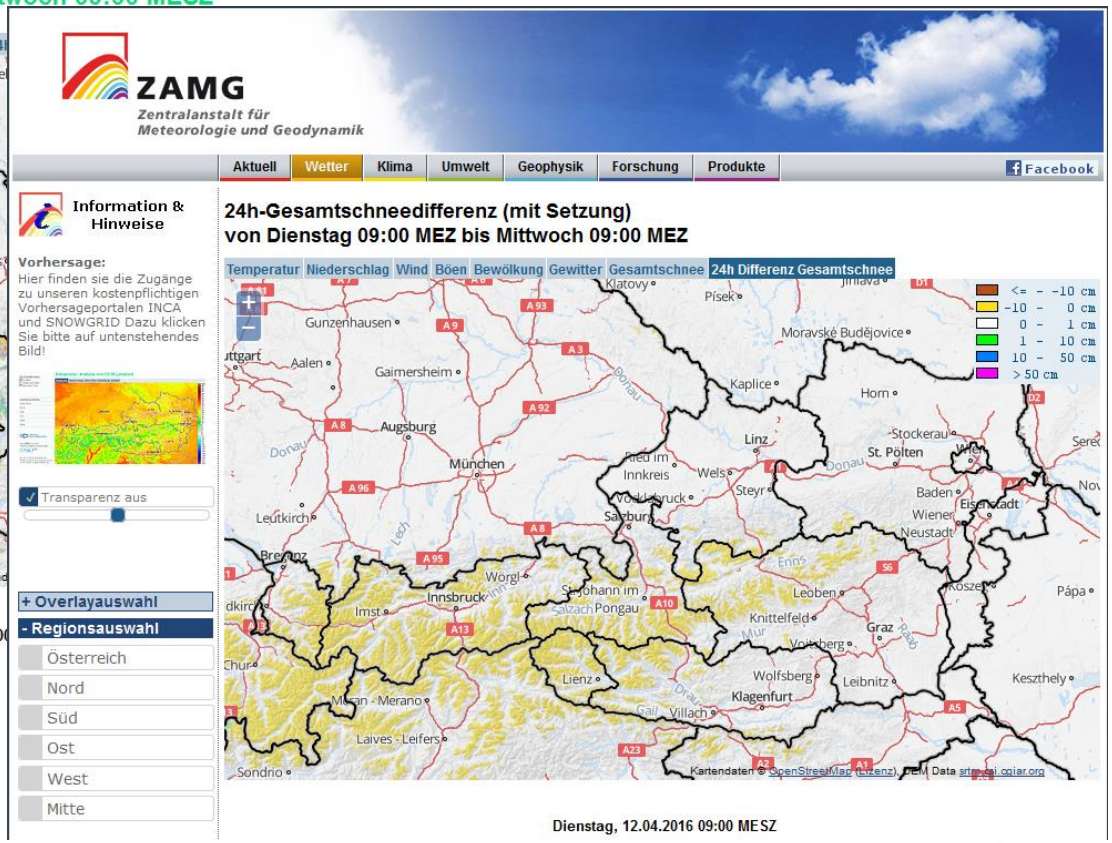
SNOWGRID Prognose der 48h-Neuschneesumme (Schneehöhe; mit Setzung, ohne Schmelze)
17-Dec-2014 06:00 UTC - 19-Dec-2014 06:00 UTC



SNOWGRID: costumer product example III

ZAMG Website (2 versions: free and for a fee)





Coupling SNOWGRID to NWP models at ZAMG

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Snow analysis using SNOWGRID

Original state (before SNOWGRID):

- no direct analysis of snow in AROME/ALARO/LAEF
- ground assimilation only indirect effect on model snow depth (via ground temperature)
- model snow depth at ini time depending on previous model forecast (precipitation, temperature,…)
- wrong model snow depth (especially yes/no) leads to significant forecast errors in e.g. air temperature especially in autumn/spring (albedo/energy balance)

→ SNOWGID offers possibility to initialize NWP snow depth (at least in parts of the domain)

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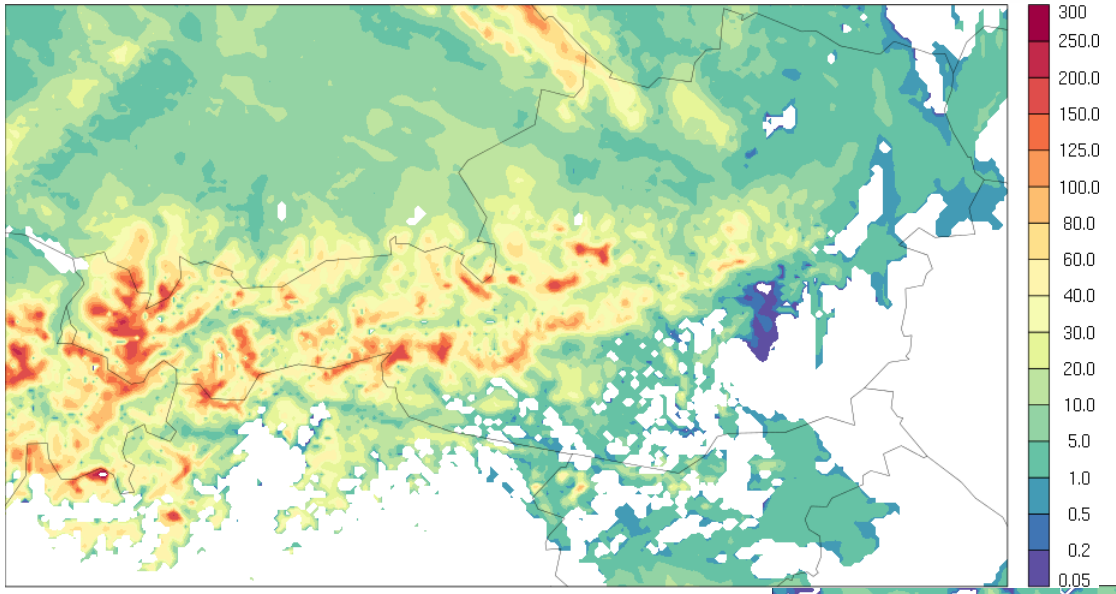
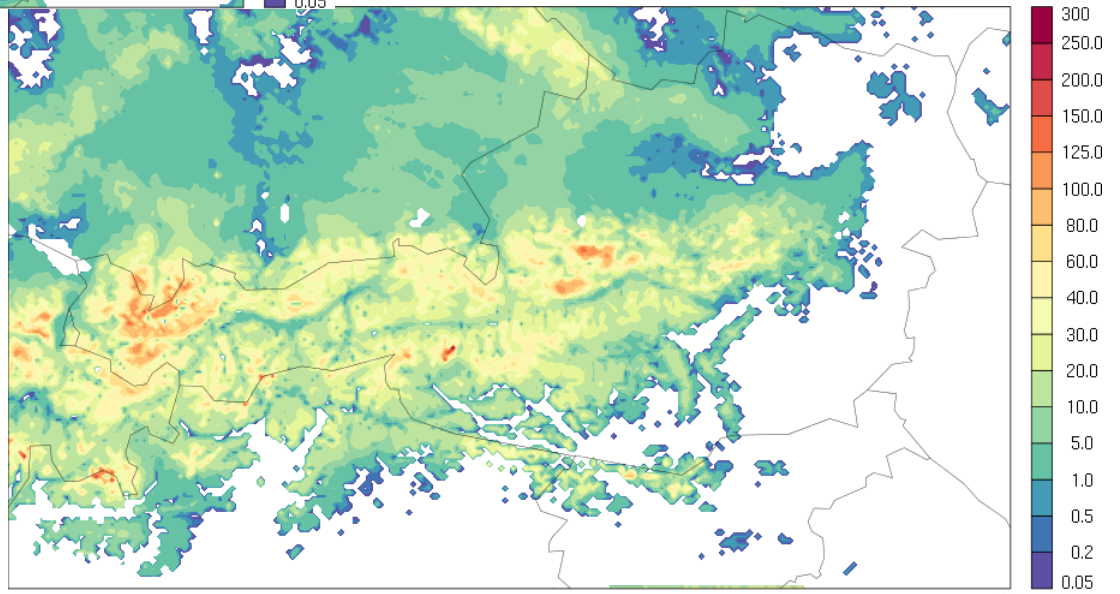
Case study 16/17 Jan 2016, Snow depth in cm



- Strong overestimation of snow depth in AROME
- Reduced snow-depth in AROME-SNOWGRID
- Corrected snow-covered area in eastern Austria in AROME-SNOWGRID

AROME-OPER

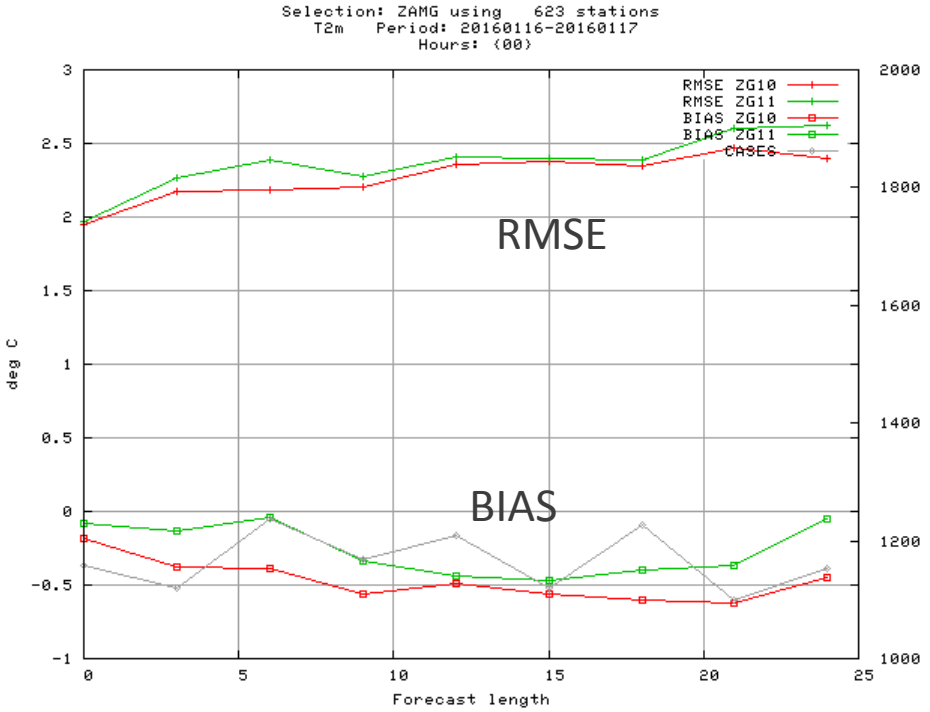


AROME-SNOWGRID

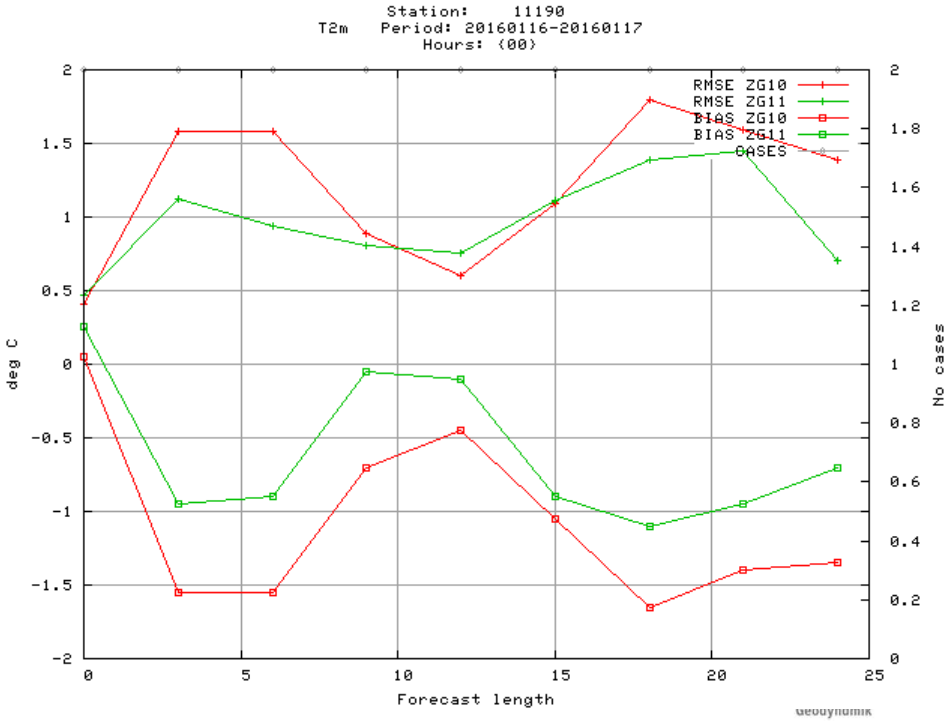
Case study 16/17 Jan 2016, Verification 2-m Temperature

- verification of 2m-temperature at stations
- significant reduction of bias at some stations with use of AROME-SNOWGRID
- Average over 623 stations: small reduction of bias
- Verifikation over longer time and many stations is neutral

Mean over 623 stations



station Eisenstadt:

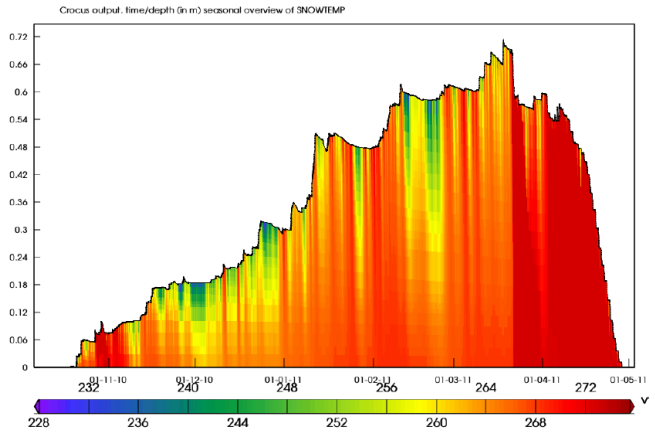


Current Status: SNOWGRID in AROME

- Use of MODIS fractional snow cover (when available) and SNOWGRID directly in AROME (using nearest neighbour interpolation)
- SNOWGRID data is set to “no data” outside of its domain

Outlook (possible future work):

- Test and coupling of AROME-SNOWGRID with CROCUS multilayer snow cover model (part of SURFEX Scheme)
- Forecasted snow profiles interesting for avalanche warning services
- Comparison and tests of sentinel vs. MODIS data



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CONCLUSIONS

Outlook

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SNOWGRID: Take home points

- ✓ Point performance: good timing of single events, absolute values are partly under-/overestimated (wind effects, precipitation input, new snow density, snowline, ground)

- ✓ Very good spatial performance (snow-covered area) (Skill score 0.75 over 2 winter seasons)

- ✓ Available dataset (as of 18 Apr 2016):
  - v1.1: Seasons 11/12 – 12/13 (Oct - May)
  - v1.3: seit 1.9.2014-ongoing
  - data of Jun-Aug is usually deleted

- ✓ Costumers are: avalanche warning services, (hydro) power companies, road services, hydrological services, mountain weather websites

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SNOWGRID: current work and outlook

- ✓ Improving current operational version:
  - ✓ degree-day model will be extended with radiation model (considering shading, slope/aspect, cloudiness, surface albedo), e.g. melt patterns of south vs. north slopes
  - ✓ Inclusion of liquid water content (state variable), runoff at each gridpoint
  - ✓ Further assimilation experiments with point and satellite data (sentinel vs. MODIS)
  - ✓ Multi-model ensemble forecast at points
- ✓ Quantitative evaluation of 72-H forecasts (ALARO/ECMWF) (snow depth and snow warnings)
- ✓ Use snow depth data to better deal with undercatch of winter precipitation (pluSnow; ongoing)
- ✓ Further experiments with full energy balance version (e.g. improve snow surface temperatures, performance issues)
- ✓ Simple parameterizations of wind induced snow transport (using wind and terrain data)
- ✓ Feasibility study of using UAV for snow monitoring in complex terrain (ongoing)
- ✓ Test of new SWE monitoring methods (GPS beneath snow cover) (ongoing)
- ✓ Climate version of SNOWGRID (daily grids back to 1961 based on new air temperature and precipitation grids), derive gridded snow climate analysis. Data available in Spring 2017. (started)

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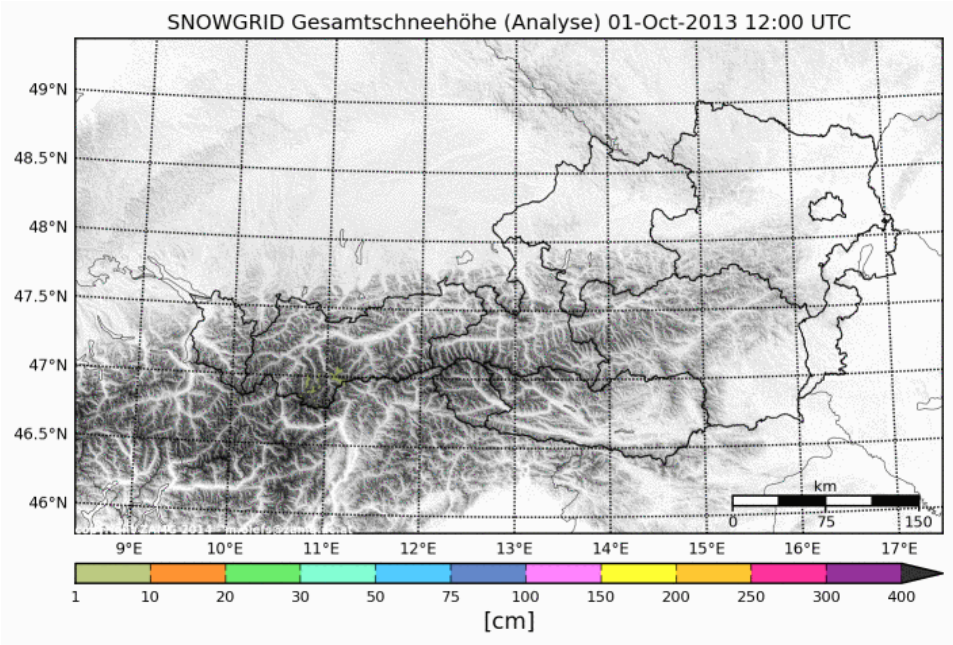
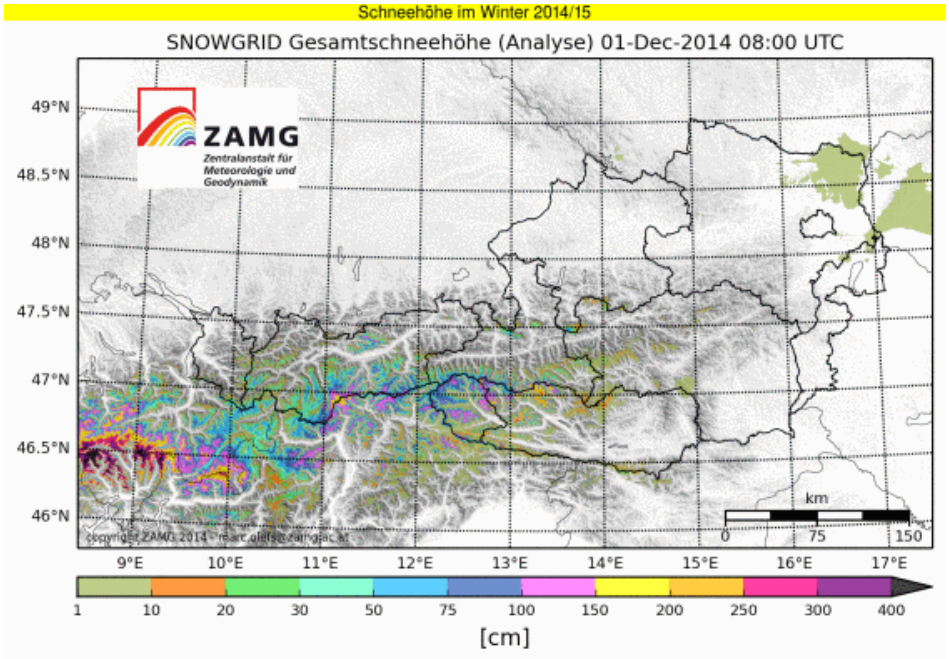
Thank you for your attention!

SNOWGRID Animations: Daily snow depths over an entire season

Winter 13/14 (Oct-Mar)



Winter 14/15 (Dec-Apr)



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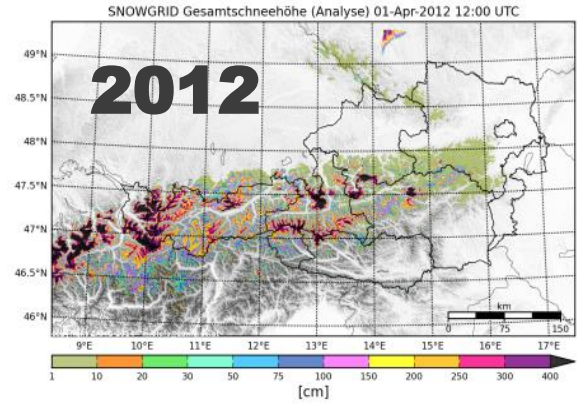
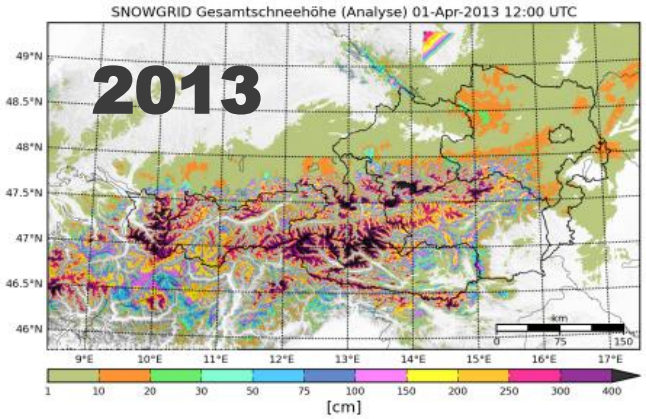
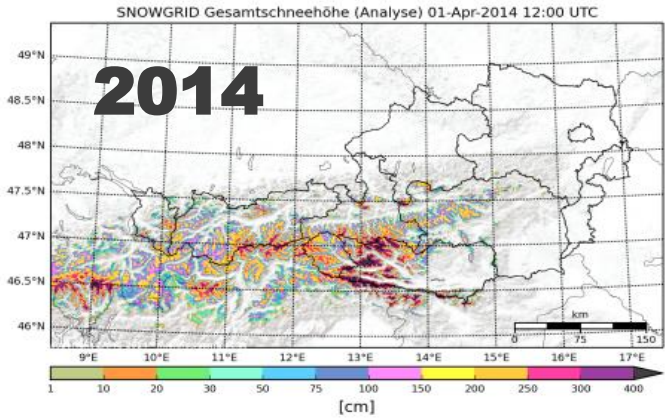
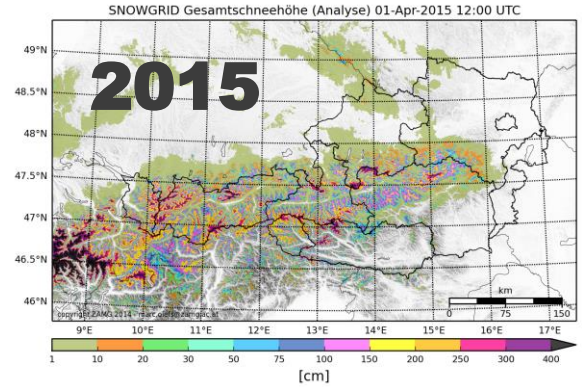
Thank you for your attention!

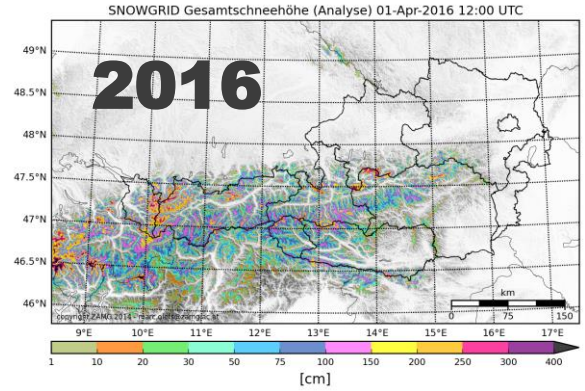
Spatial snow patterns : a seasonal perspective (1st of April 2012-2016)











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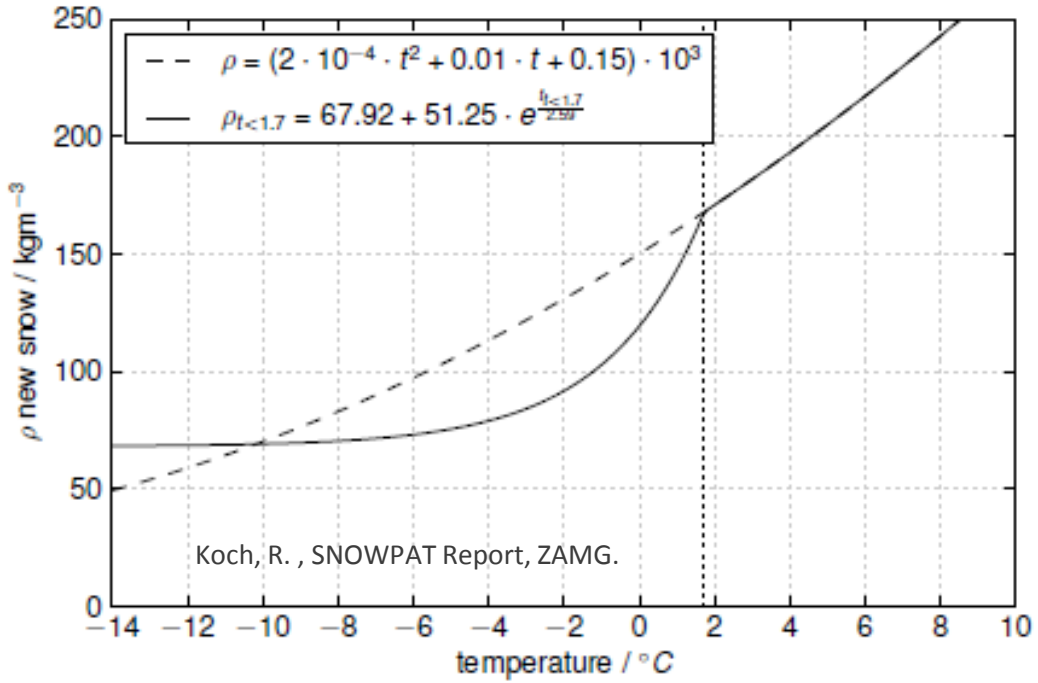
SNOWGRID: Methodik Schneemodell

Fresh snow density in SNOWGRID



Density of fresh snow = f(air temp.)
Combination of 2 formulaes:
Schwellwert bei +1.7°C
limits: [50, 210] kg/m³
Koren et al. (1999), US Army (1956)

Possible future upgrades: include wind and or wet-bulb temperature

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SNOWGRID: Methods and technical stuff

Snowline depression induced by cooling of melting precipitation

Effect gets activated if:

Initial snowline from INCA/ALARO (1.5°C wet-bulb temp.): < crest height & > ground

AND

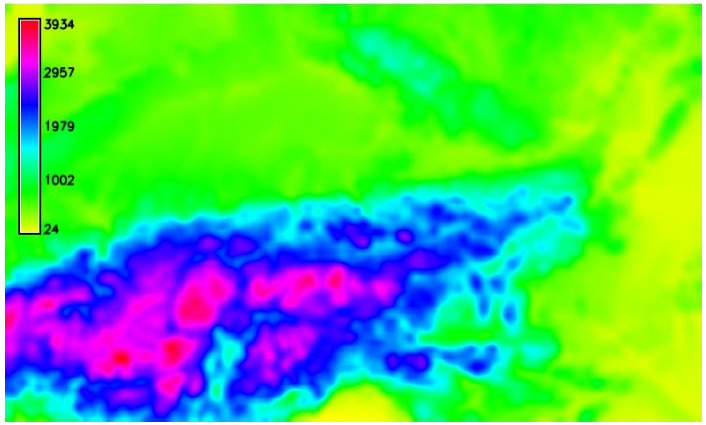
Sky view factor < 0.9 (< 90 % visible sky → no effect in summit regions, planes (larger ventilation))

Amount of cooling/depression depending on:

Air column ground – initial snowline altitude

Precipitation intensity

→ Calculation of snowline depression using wet-adiabatic temp gradient



Kammhöhe INCA-L Domain

Solve heat balance equation:

$$\rho_{H2O} * rr * l_f = c_p \rho_{air} * dh * dT$$

Future upgrade: include wind information (dampening effect)

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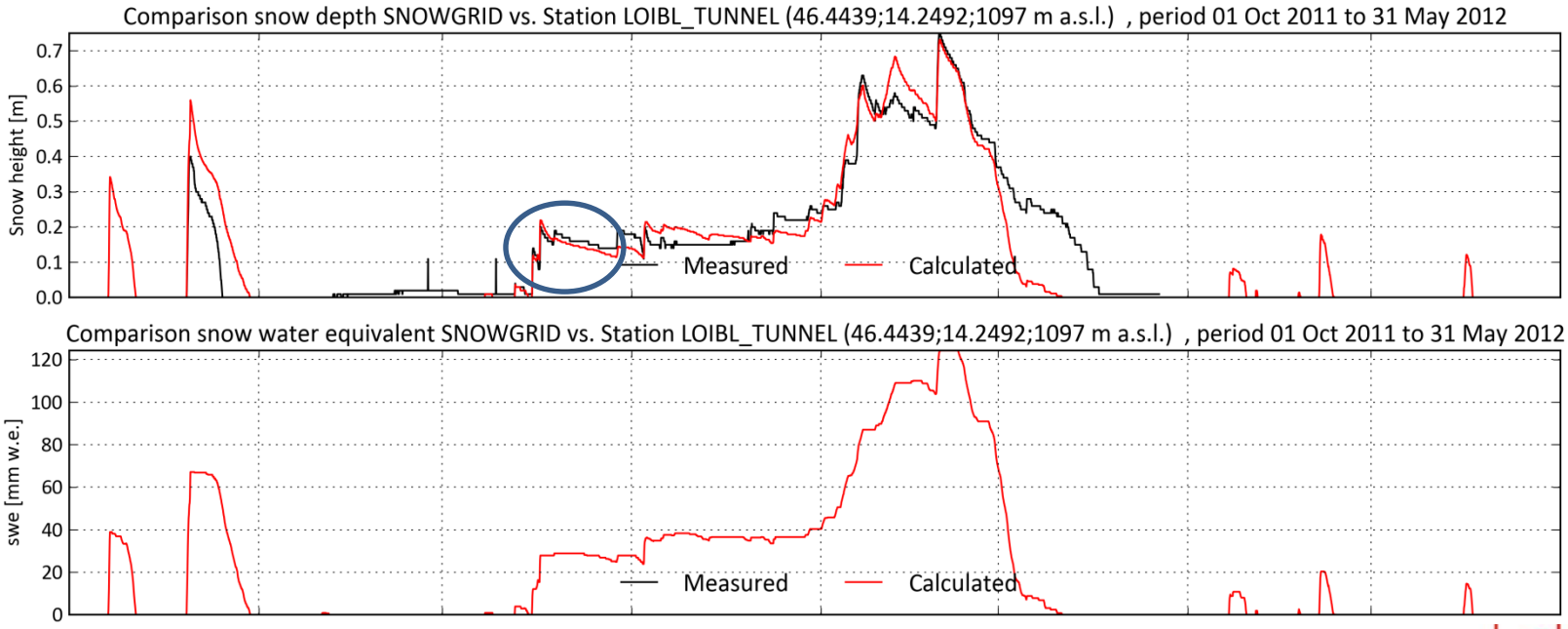
SNOWGRID: Methodik Schneemodell

BACK

Setzung

- Nach Schneefall erst schnelle Setzung - destruktive Metamorphose (gedämpft ab 150 kg/m³)
- Dann dichteabh. langsamere Setzung durch Auflast, derzeit melt compaction (noch) vernachlässigt
- Algorithmus von Neururer / Jordan (1991), SNTHERM. f(airtemp, swe_new, rho)



Mögliche Upgrades/Tests: hinzufügen „Schmelzkompaktionsterm“

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SNOWGRID: Methods and technical stuff

BACK

Heat content of the snow cover

- Fresh snow gets wet-bulb temperature of the air
- average snow temp = weighted average fresh and old snow (using SWE)
- during each time step: difference air vs. snow temperature in/decreases cold content
- Effective ablation only possible if cold content of snow cover = 0

Factors influencing the cold content:

- Temperature of fresh snow
- Difference average snow vs. air temperature
- Liquid precipitation (temperature difference and latent heat)
- Rapid heating of the snow in case of rain on (cold) snow events (latent heat release)

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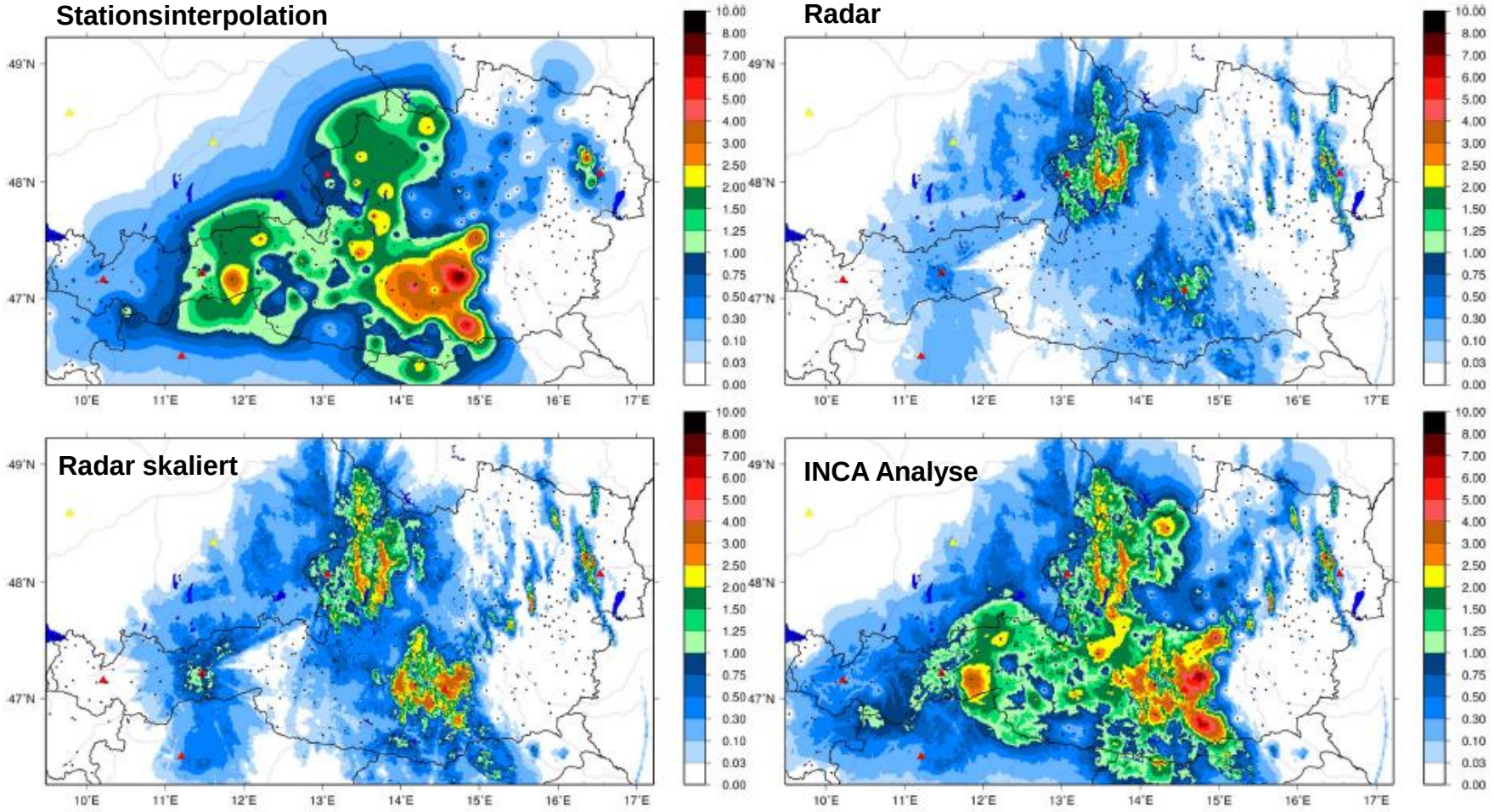
SNOWGRID: Methodik Schneemodell

INCA-precipitation



18 July 2009, 07:30 UTC

In wintertime (Tl< 0°C): constant +30 %

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