High frequency measurements over an instrumented profile tower in Dome C Antarctica ; attempting to estimate some turbulent parameters through unstable and stable boundary layer conditions above snow surface

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... and many colleagues from other labs.

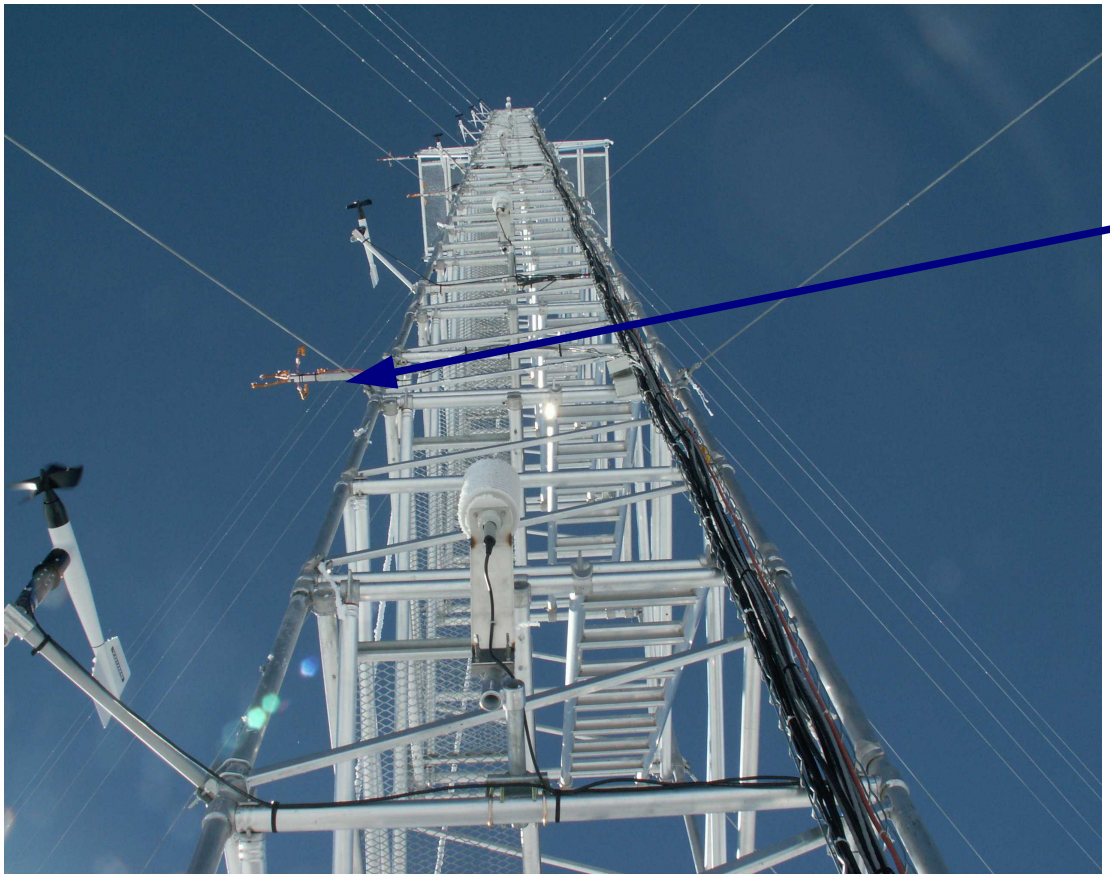
Toulouse, may 2013

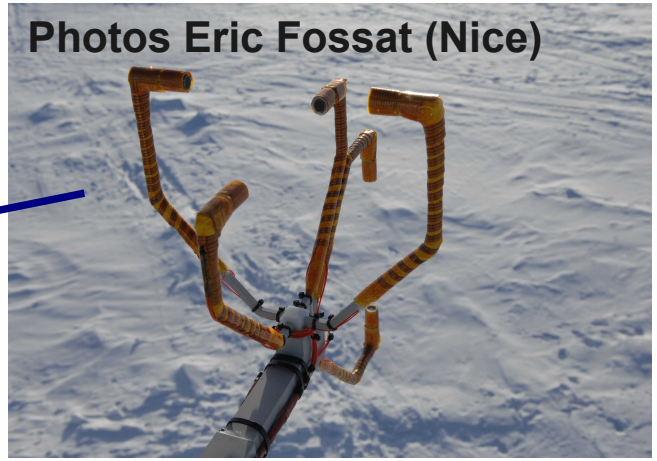
Dome C / Concordia base : a very convenient site to study snow-atmosphere interactions

-Flat, horizontal and quasi-infinite terrain
-Relatively homogeneous snow surface
-Moderate wind velocity
-High diurnal cycle
-Sophisticated instrumentation
-BSRN radiation observations
-LGGE/IPEV and PNRA boundary layer and surface observations
-LGGE continuous snow temperature profiles
-LGGE detailed density, temperature and SSA profiles in Summer
-Radio-soundings (two per day during Concordiasi field campaign)
-Importance of boundary layer and snow pack studies also for atmospheric chemistry, particularly on the Plateau (example: South Pole work by the Americans and DC i.e. Markus Frey paper).

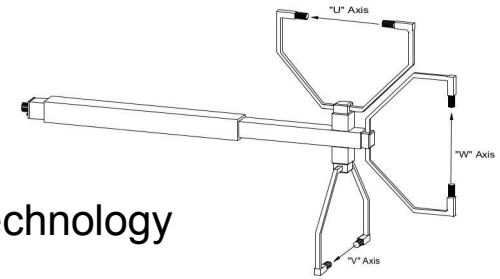
Dome C : Astronomers and their 45 meters high tower ...

The lower atmospheric boundary layer at Dome C is monitored since January 2008 (Genthon et al., J. Geophys. Res., 2010). Anemometers, thermometers and hygrometers are deployed at 6 levels above the surface upto ~45 m. Thanks to astronomers (UN, Fizeau), 6 ultra-sonic thermo-anemometers provide 10 hz data.





"K" Probe - Positive Direction



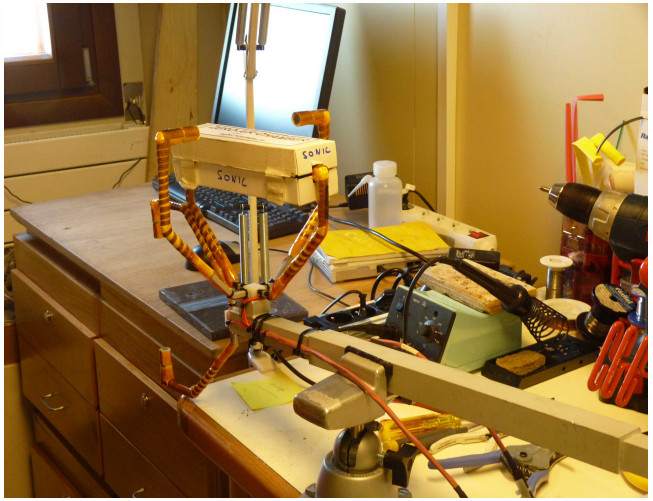
Applied Technology

Dome C : Characterizing atmospheric turbulence ...

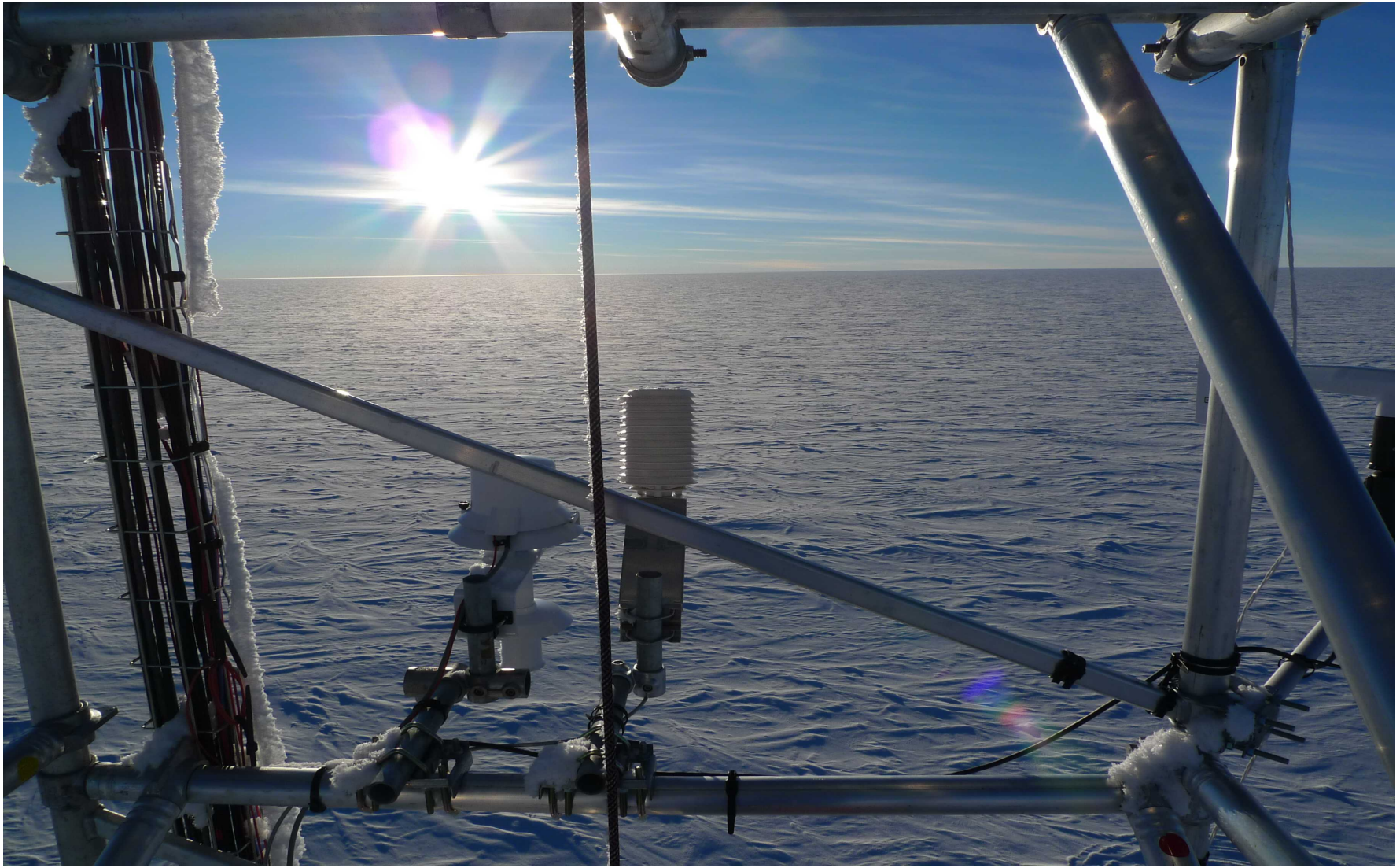
Operating and processing sonic anemometers and thermometers is particularly difficult but it provides direct measures of turbulence parameters within those extreme boundary layers.

Beyond the determination of the free atmospheric seeing and CN^2, the question is : can we obtain meteorological turbulent fluxes or TKE ?

We will see that validating evaluations of turbulence in such particular conditions is not so easy...



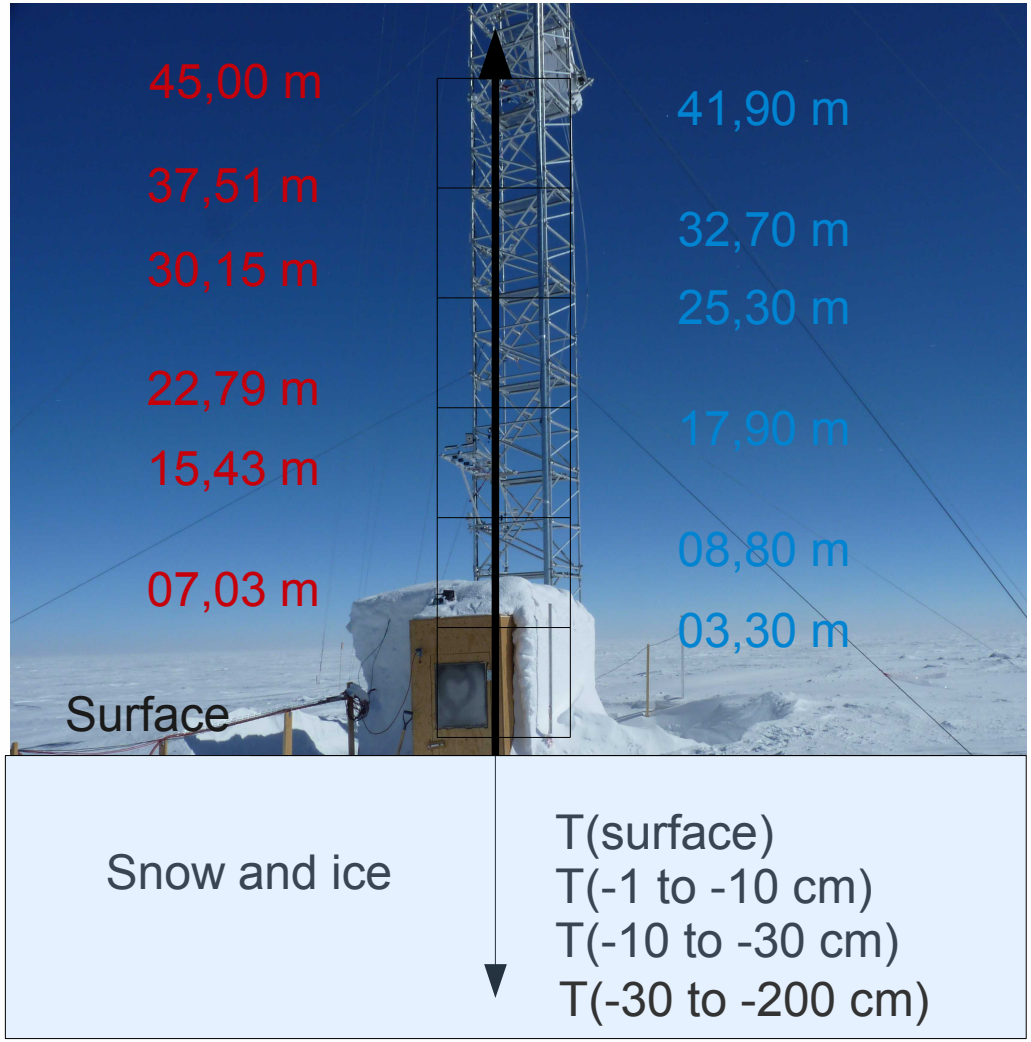
Dome C / Concordia : flat, you said flat ..



Boundary layer observation from a 45m tower (LGGE)

1- Instrumental device description

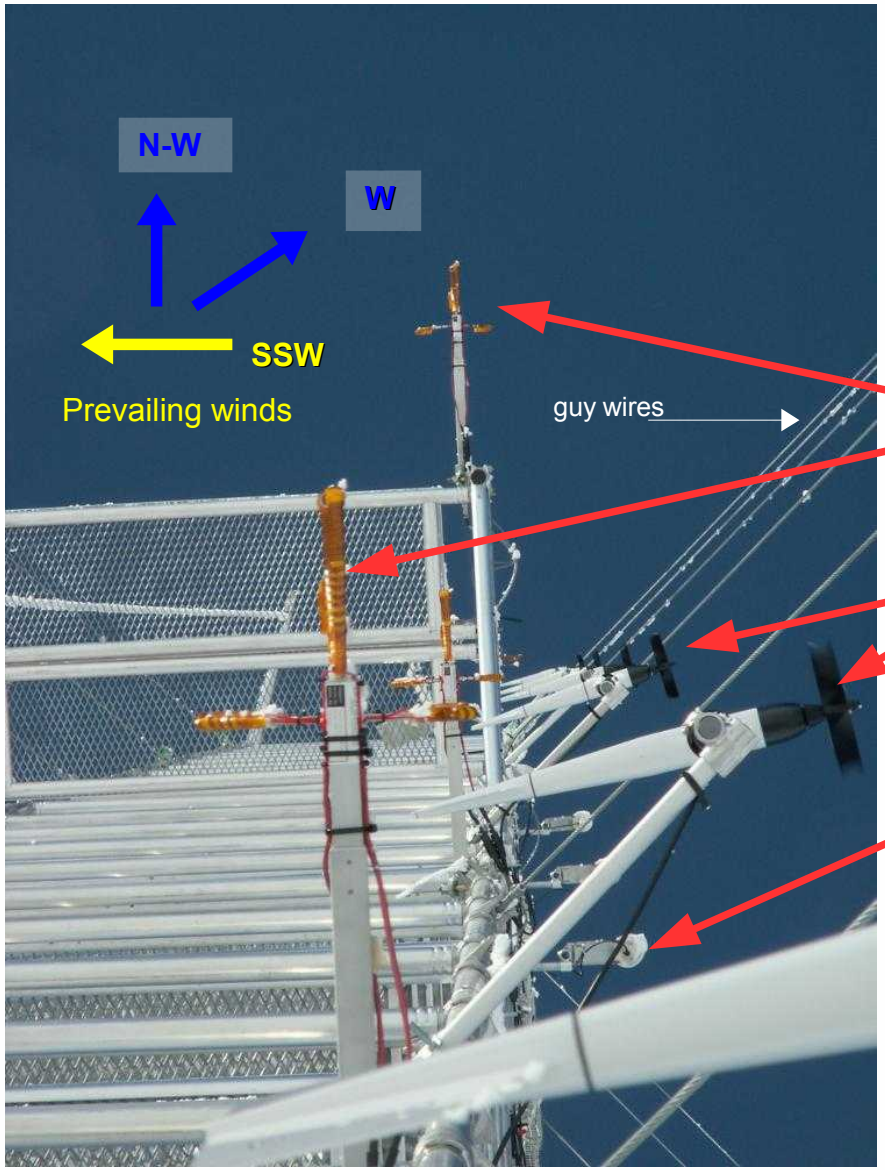
« American » tower



1. High frequency parameters (10 Hz) from 6 ultra-sonic anemometers :
   3D Wind components and sonic temperature
2. Low frequency parameters (30 min) : air temperature (ventilated and not ventilated), relative humidity, wind speed and direction.
3. 1 minute solar radiation components
4. Sub and surface temperatures

2 - Instrumental device description

Courtesy of FISEAU (Nice), LGGE (Grenoble), ISAC (Bologna), PNRA, BSRN, BAS



45-m instrumented tower with multi levels wind sensors :

sonics

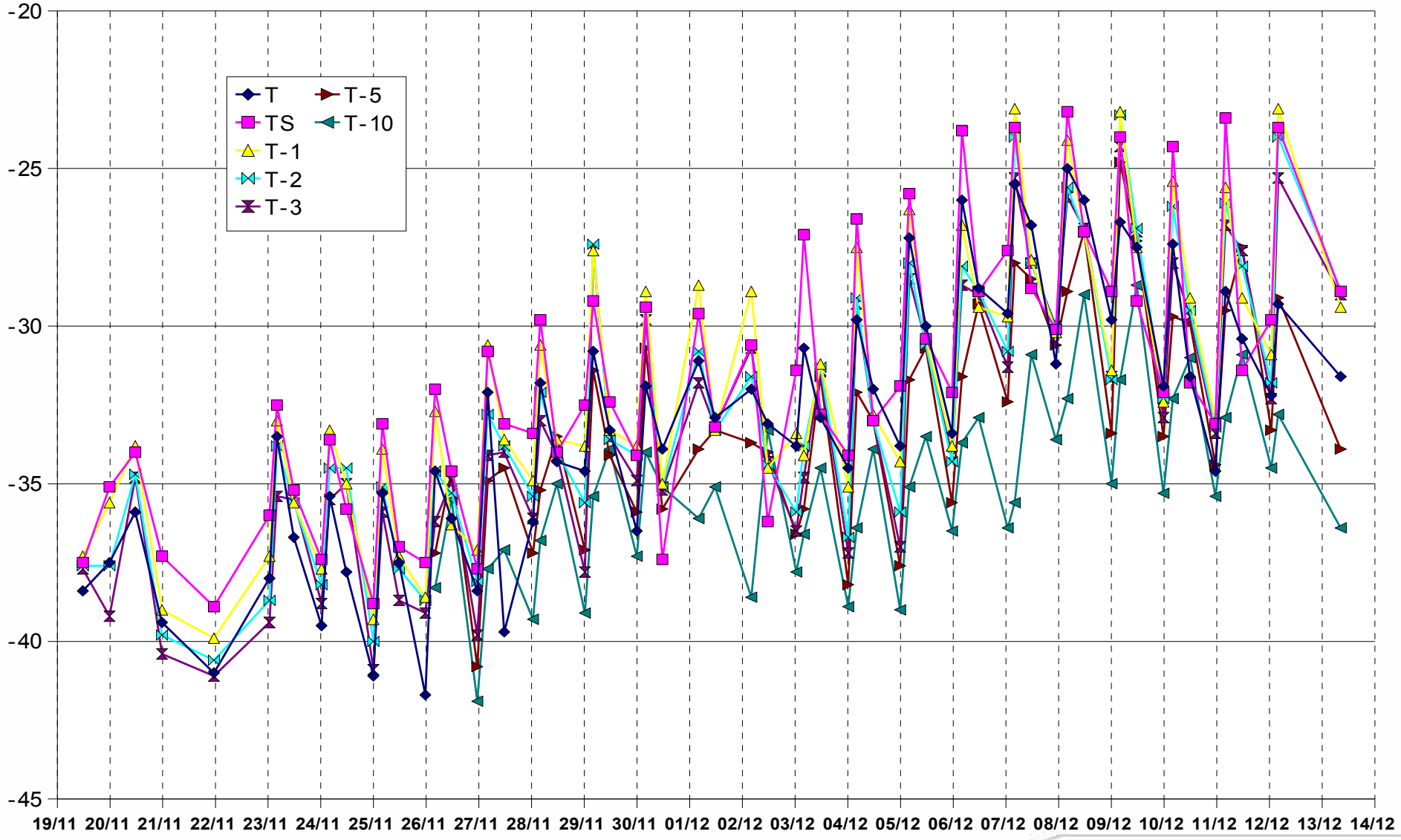
propellers

humidity and temperature probes with radiation shielded sensors, ventilated or not

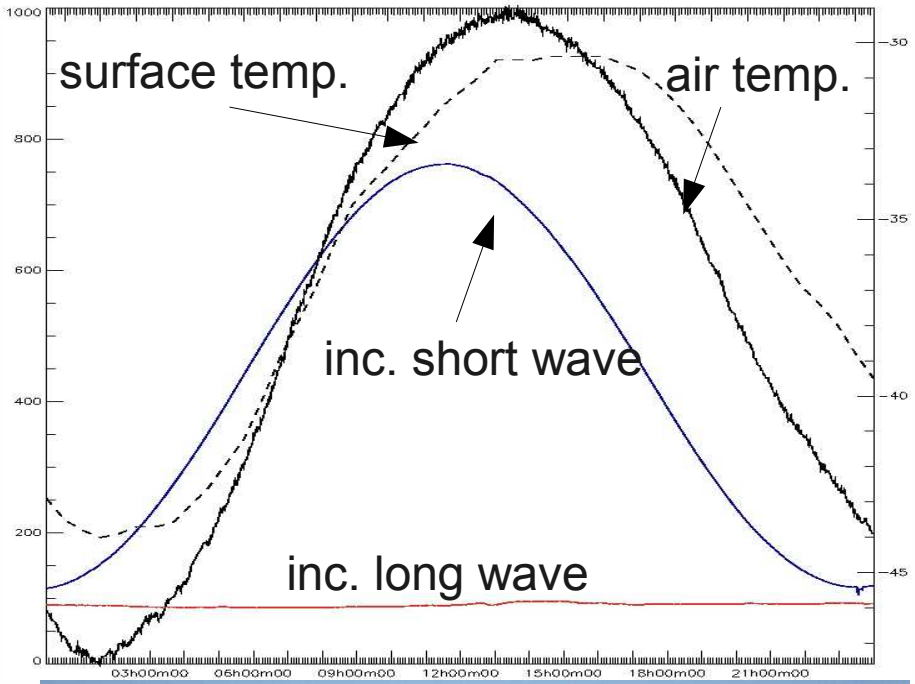
Summary of available data

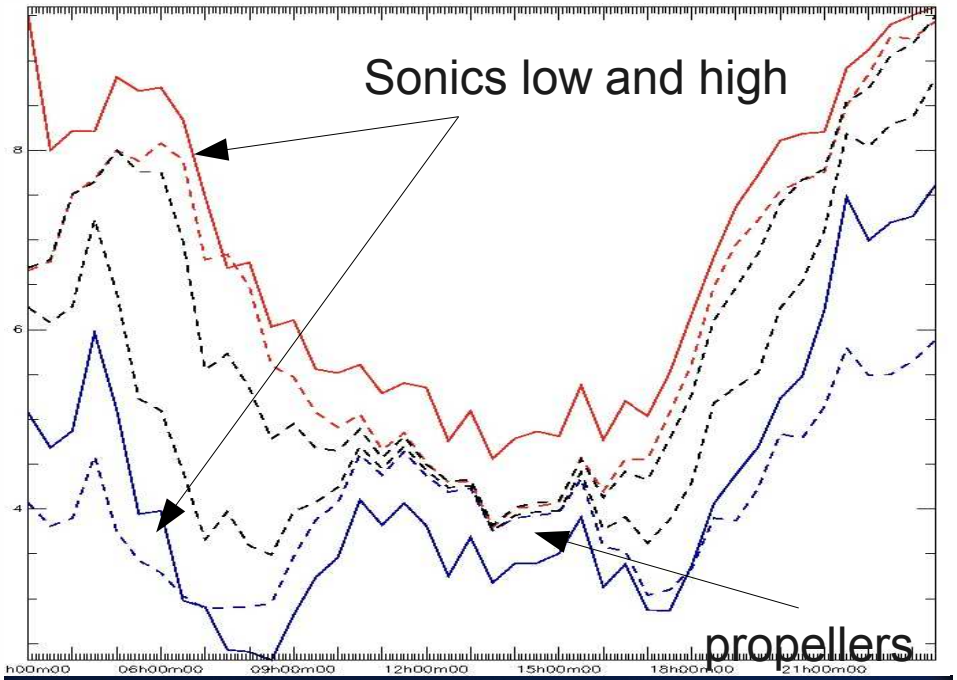
Data Logger	Sensor	Manufacturer	Frequency	Parameters Measured or calculated	Available Period of observations
Linux OS on PC	Heated Ultra-sonic anemometers	Applied Technology	10 Hz 5 min 6 m. heating	**6 levels 3D wind components m/s** **Sonic temperature (°C)** → Tair, TKE, ustar, ECM SHF	mid 2008 - 2010
CR1000 CAMPBELL SCIENTIFIC	HMP45 HMP155	VAISALA	30 minutes	**6 levels air temperatures and Relative humidities from radiations shielded (Socrima) ; not ventilated** → Specific and absolute humidity → Mixing ratio and potential temperature	2008 - 2010
CR1000	PT100		30 minutes	**6 levels ventilated air temperatures**	2008 - 2010
CR1000 CAMPBELL SCIENTIFIC	Propellers anemometers	YOUNG	30 minutes	**6 levels Wind speed and direction**	2008 - 2010
	Pyranometer CM22	KIPP & ZONEN	1 minute	**Short Wave radiation**	mid nov. 2009 - jan. 2010
	Pyrheliometer CH1	KIPP & ZONEN	1 minute	**Direct radiation**	//
	Pyrgeometer CG4	KIPP & ZONEN	1 minute	**Long wave radiation** → Surface temperature	//
				-10 cm temperature **-20 cm //** **-30 cm to -200 cm temperatures**	mid nov. 2009 - jan. 2010
	Manual measurements			**Surface, -1,-2,-3,-4,-5,-6,-7,-8,-9,-10 cm temperature**	mid nov. 2009 - mid dec. 2009
DIGICORA III Sounding System	RS92-SGP	VAISALA	2 seconds 0nce or twice a day	**P, T, U, WD, WS profiles**	mid nov. 2009 - jan. 2010
	Manual measurements			**Visibility and Cloud cover**	mid nov. 2009- mid dec. 2009

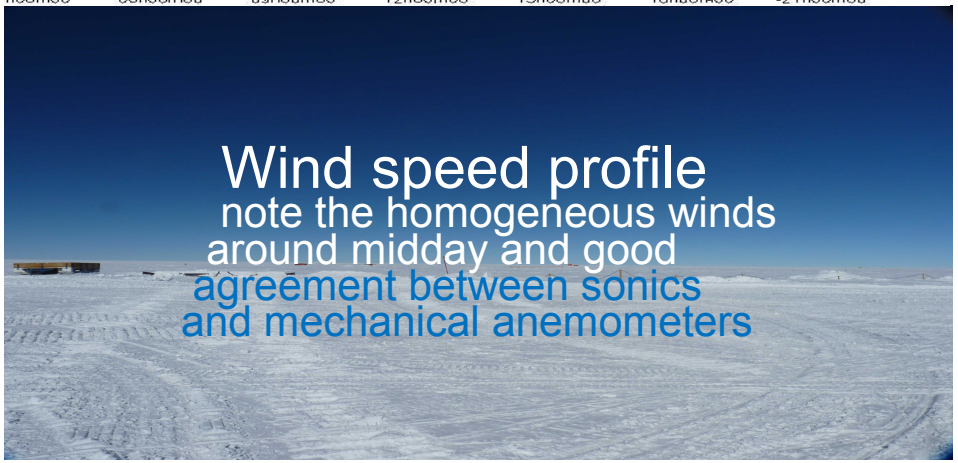
Hand-made surface temperature and from -1 to -10 cm every cm, 11/19 to 12/14 2009



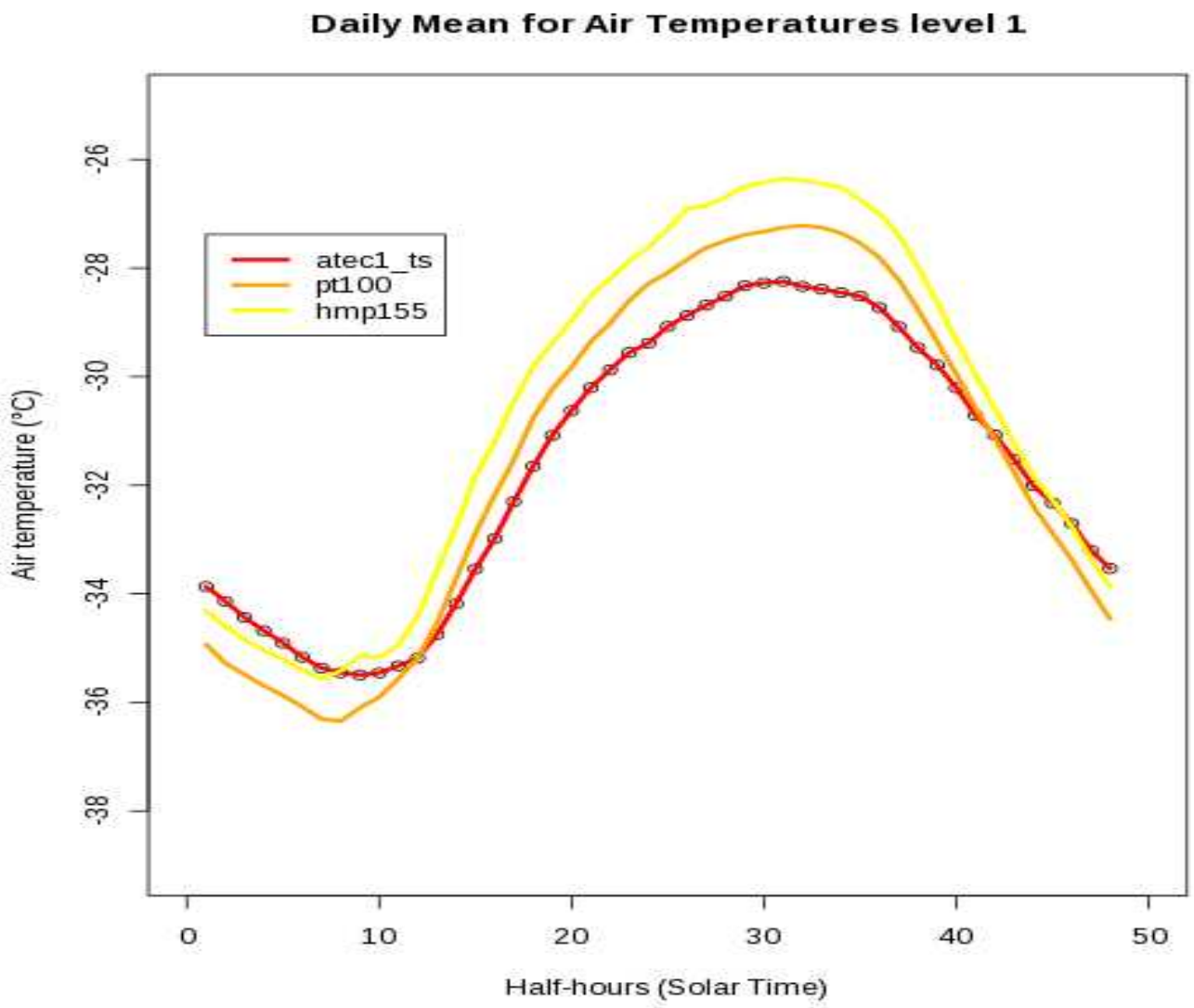
Wind speed profiles, radiations and temperatures



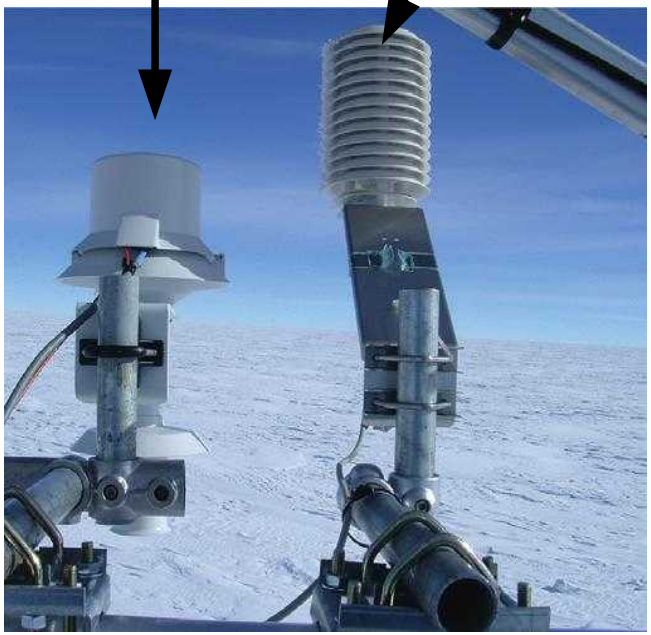




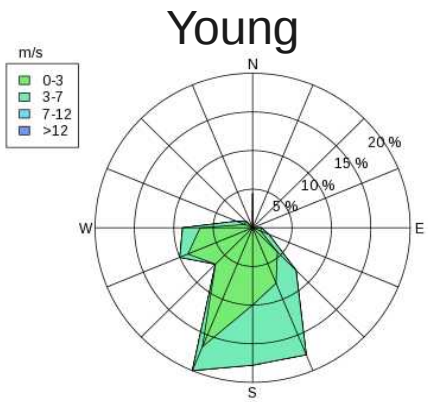
Three air temperatures at level 1 from 12/01/2009 to 01/31/2010

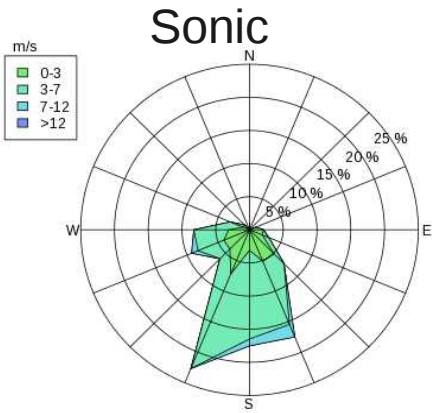


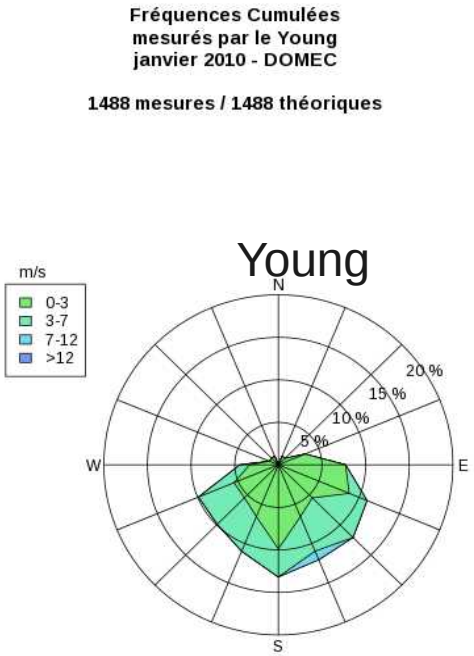
FV(pt100) NV(hmp)

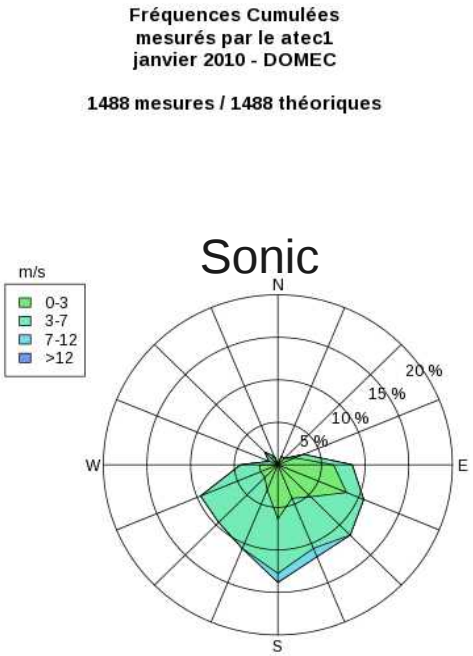


Wind Roses sonic VS Young from 12/01/2009 to 01/31/2010





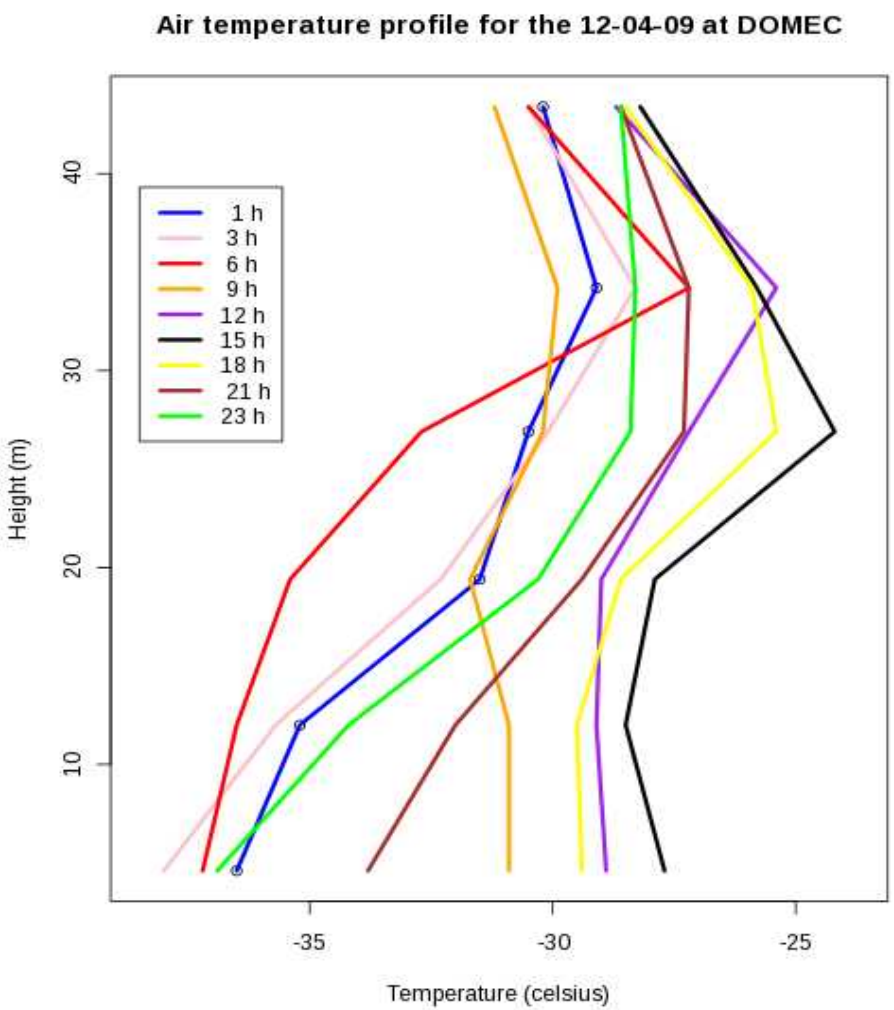


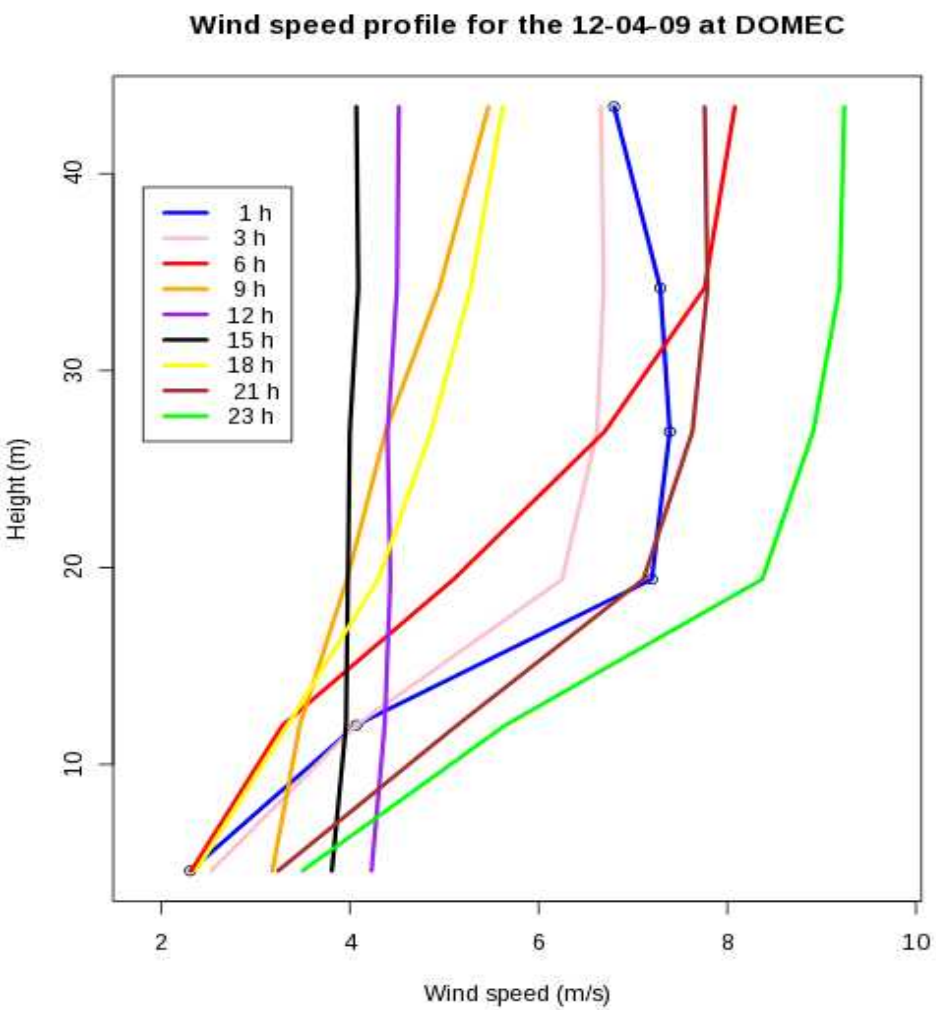


December 2009

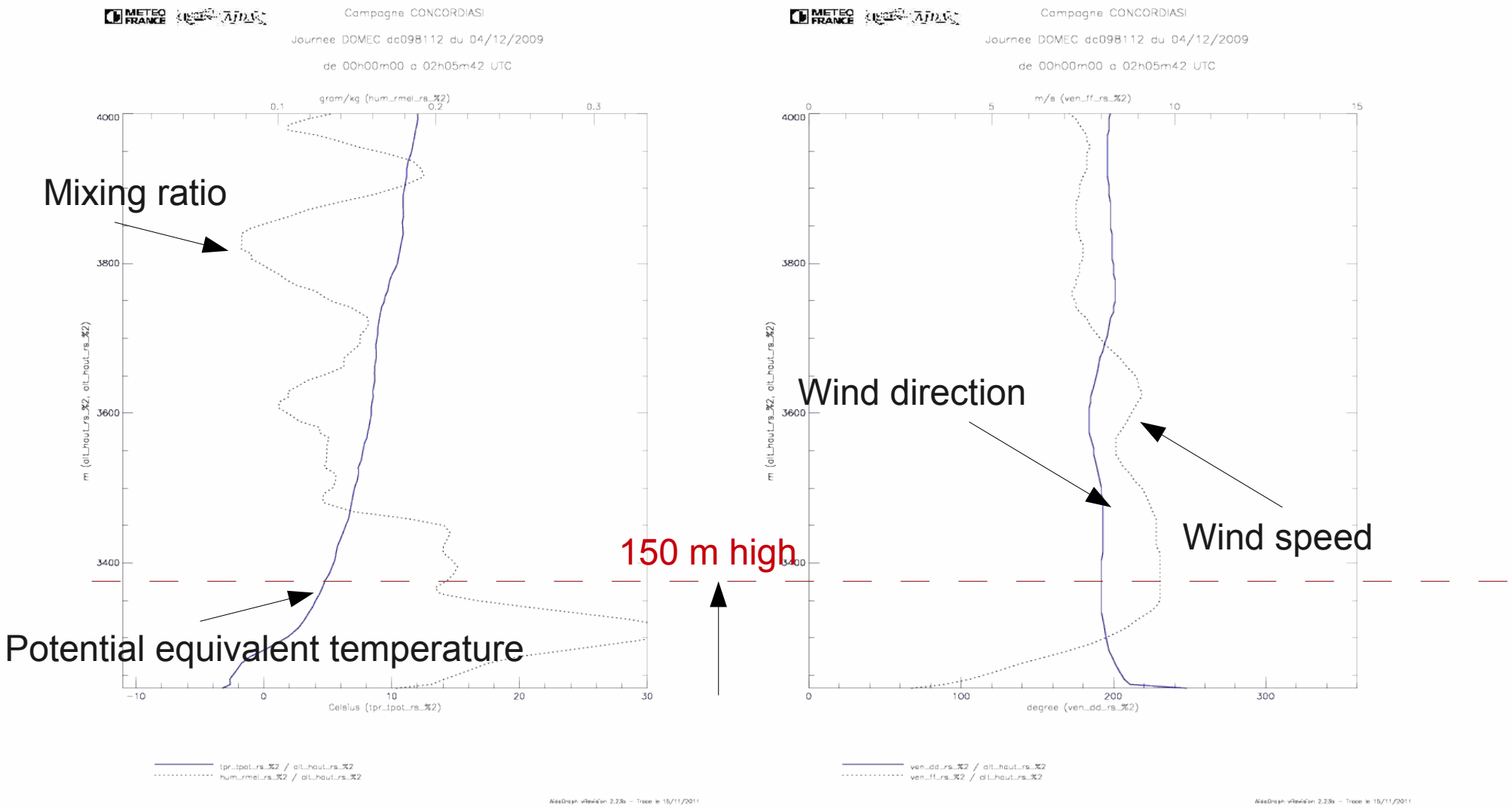
January 2010

Temperature and wind speed profiles

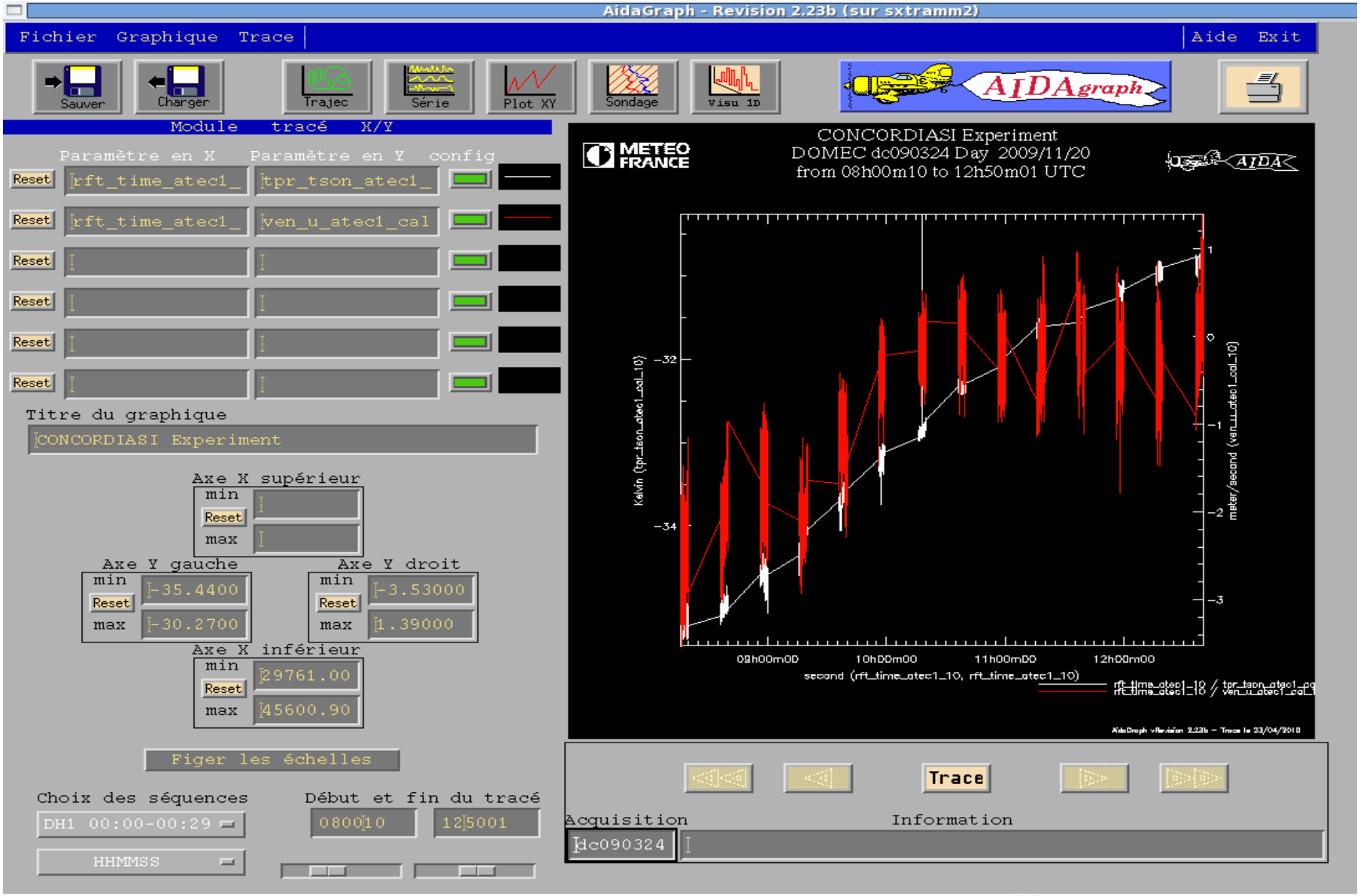




Radio-soundings profiles

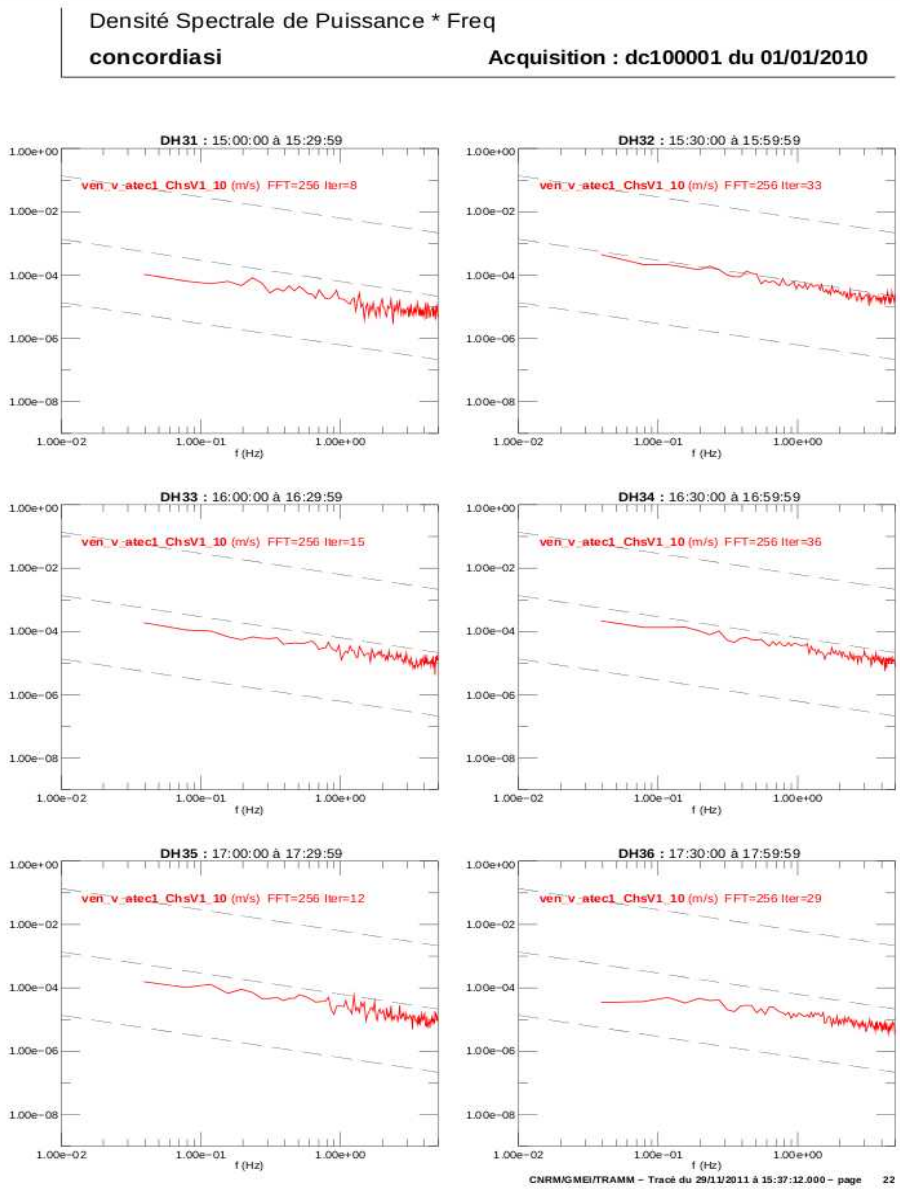


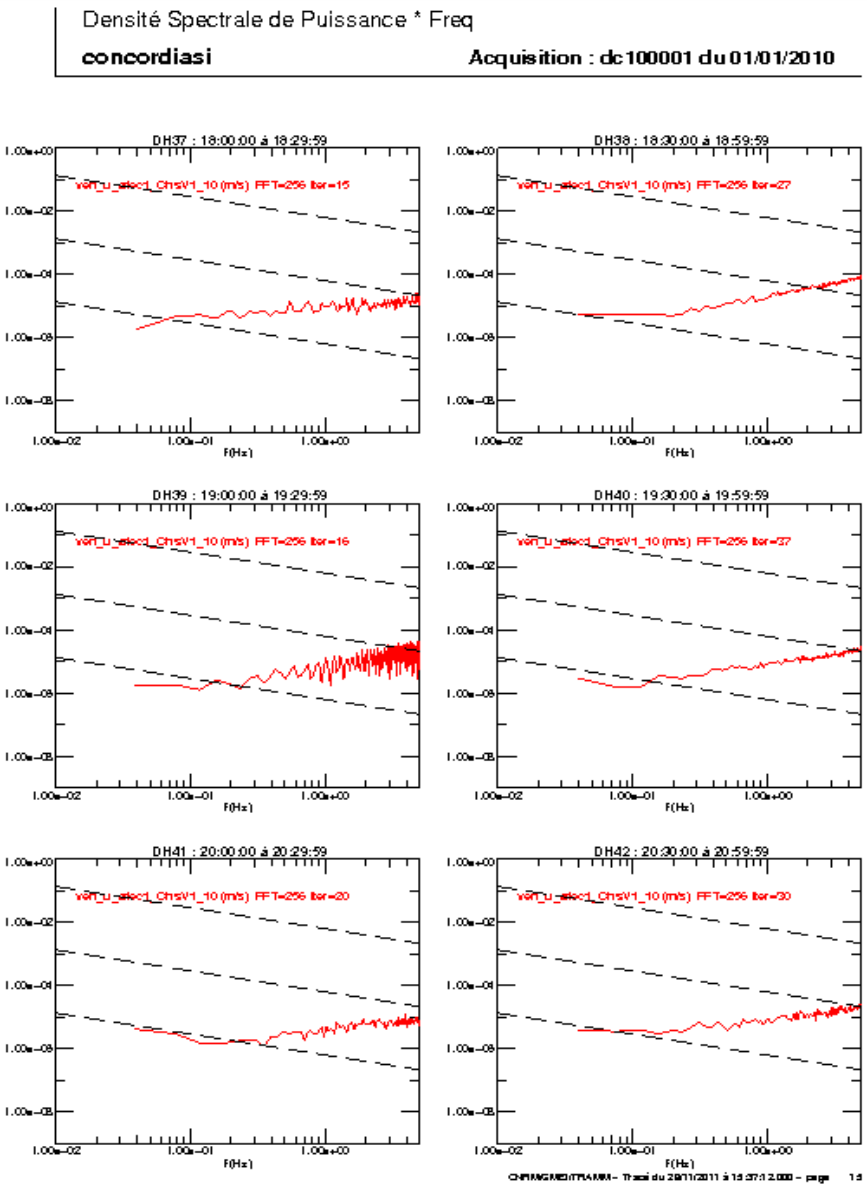
Aida Interface for data post-processing (CNRM/GMEI/TRAMM)



METEO FRANCE
Toujours un temps d'avance

Power spectral density : -5/3 ?





Eddy-Covariance method : what to do with sonics?

Raw data (10 Hz) are :

- cleaned (real data, in/out range)
- despiked
- 2-rotated (in the mean wind plan so that <v> and <w>=0
- Running-mean filtered (high pass ; Tau=200 s)

Assumptions :

- real air temperature is the one given by the sonic (very dry air, 0.3 g/m3)
- pressure (not measured) is supposed to be constant for each level (less than 1hPa between each measurement), and also for the air density (0.8 kg/m3)
- Kolmogorov and similitude laws are applied (to be verified : cf. spectrum density, sigmaX/X*)

Eddy-Covariance method : theory

In turbulent flow, vertical flux can be presented as:
($s=\rho_c/\rho_a$ is a mixing ratio of substance 'c' in the air)

$$F = \overline{\rho_a w s}$$

Reynolds decomposition is used then to break into means and deviations:

$$F = \overline{(\overline{\rho_a} + \rho'_a)(\overline{w} + w')(\overline{s} + s')}$$

Open parenthesis:

$$F = \overline{(\overline{\rho_a}\,\overline{w}\,\overline{s} + \overline{\rho_a}\,\overline{w}\,\overline{s'} + \overline{\rho_a}\,\overline{w'}\,\overline{s} + \overline{\rho_a}\,\overline{w's'} + \overline{\rho'_a}\,\overline{w}\,\overline{s} + \overline{\rho'_a}\,\overline{ws'} + \overline{\rho'_a}\,\overline{w's} + \overline{\rho'_a w's'})}$$

Averaged deviation from the average is zero

Equation is simplified:

$$F = (\overline{\rho_a}\,\overline{w}\,\overline{s} + \overline{\rho_a}\,\overline{w's'} + \overline{w}\,\overline{\rho'_a s'} + \overline{s}\,\overline{\rho'_a w'} + \overline{\rho_a' w's'})$$

Eddy-Covariance method : theory

Then important assumption is made (for conventional Eddy Covariance) – density fluctuations are assumed negligible:

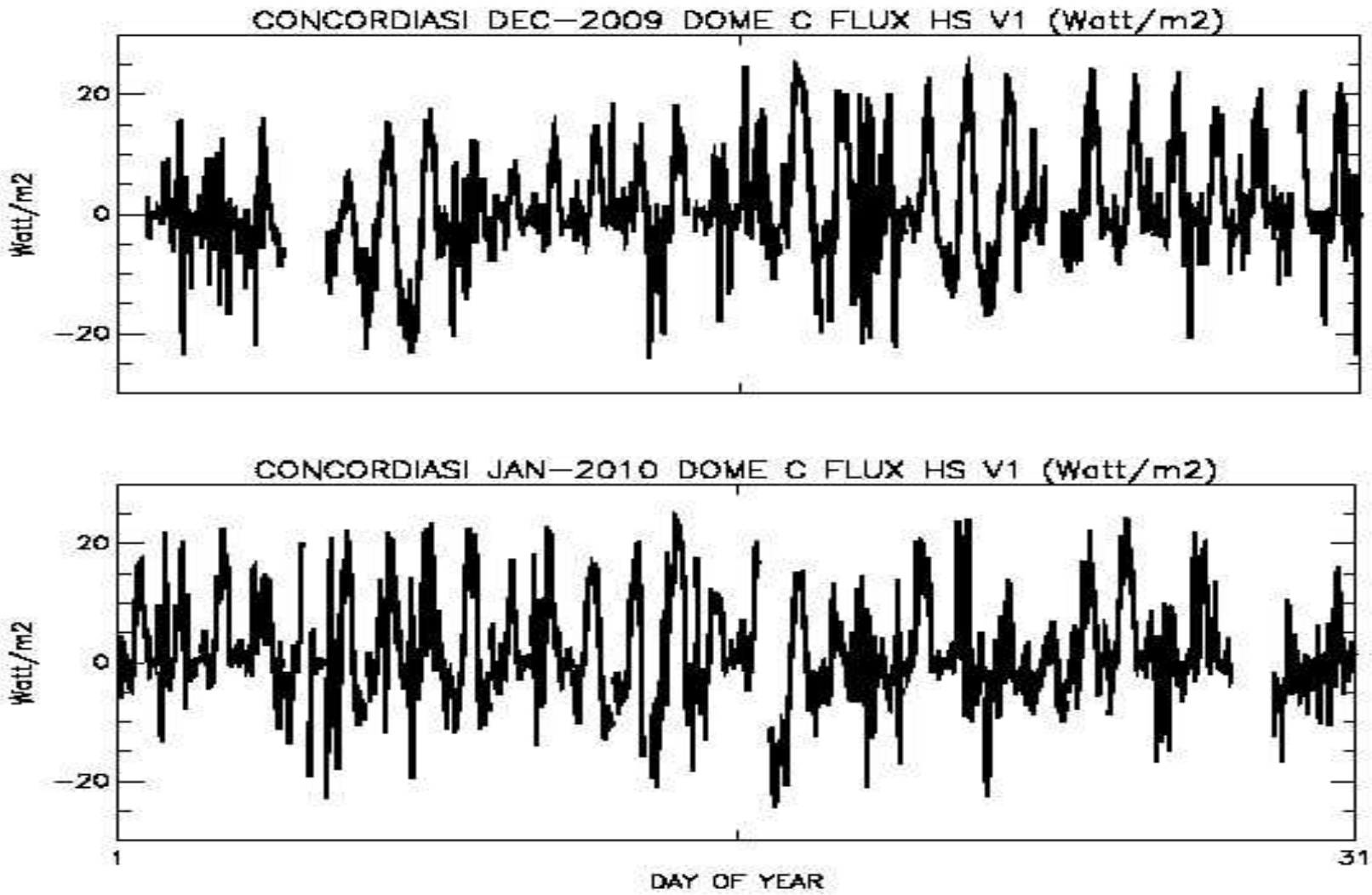
$$F = (\overline{\rho_a}\,\overline{w}\,\overline{s} + \overline{\rho_a}\,\overline{w's'} + \overline{w}\,\cancel{\overline{\rho'_a s'}} + \overline{s}\,\cancel{\overline{\rho'_a w'}} + \cancel{\overline{\rho'_a w' s'}}) = \cancel{\overline{\rho_a}\,\overline{w}\,\overline{s}} + \overline{\rho_a}\,\overline{w's'}$$

Then another important assumption is made – mean vertical flow is assumed negligible for horizontal homogeneous terrain (no divergence/convergence):

$$F \approx \overline{\rho_a}\,\overline{w's'}$$

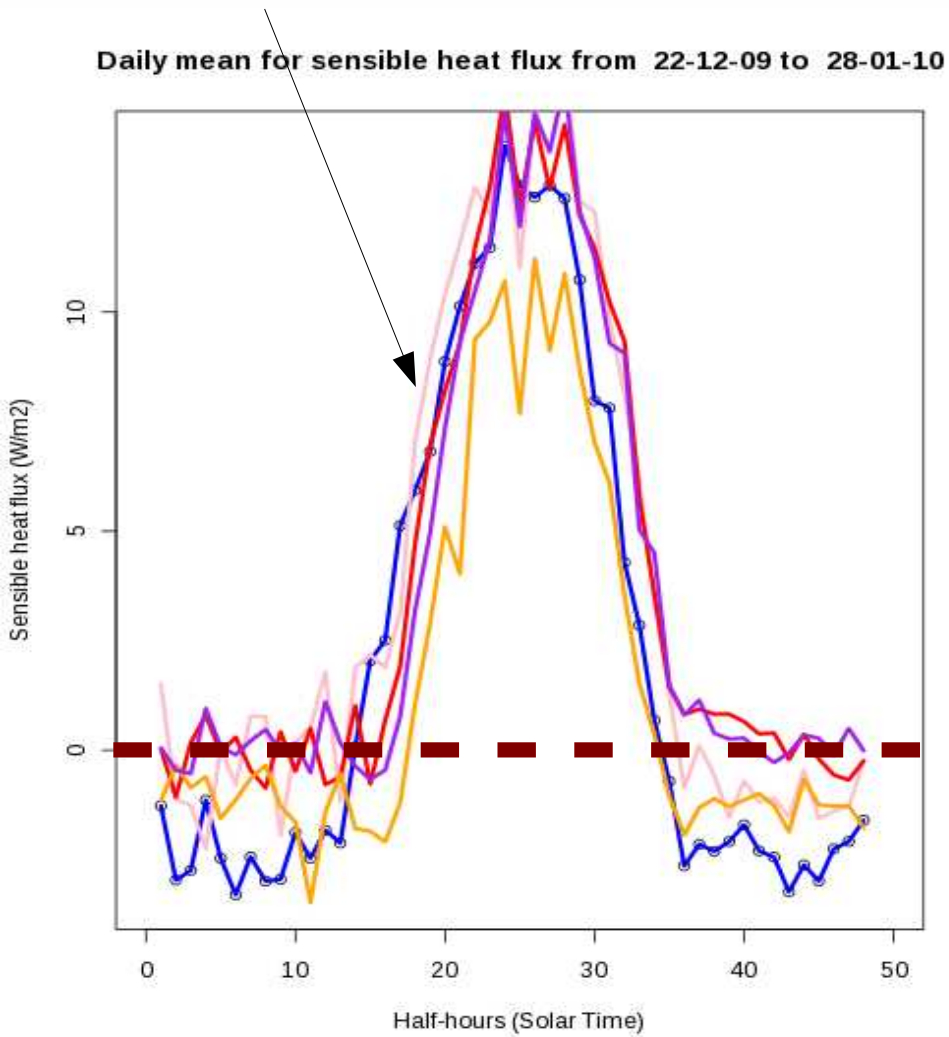
'Eddy flux'

Sensible heat flux
from 12/01/2009 to 01/31/2010



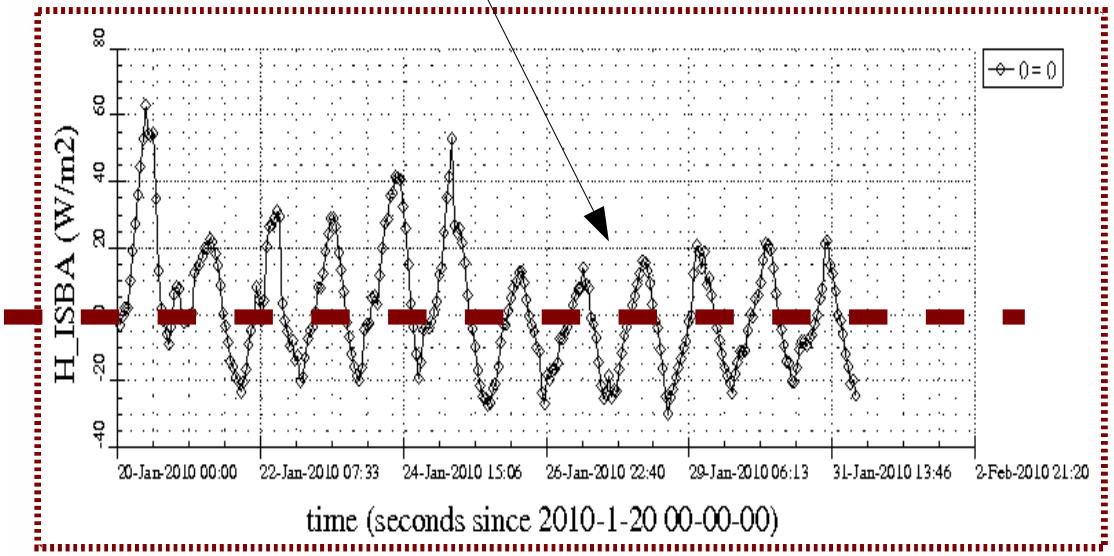
Sensible heat flux
1 month mean : from 12/22/2009 to 01/28/2010

5 levels



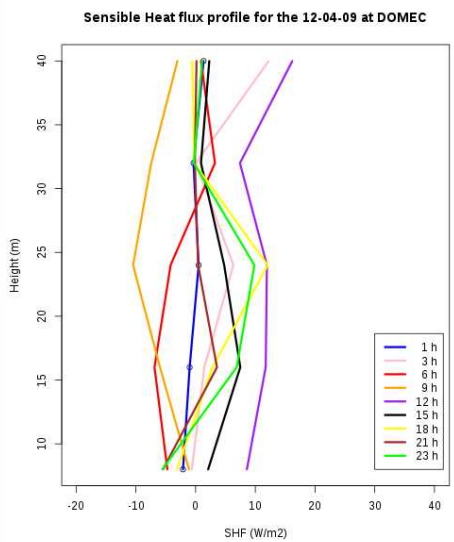
Eddy-Covariance Methode

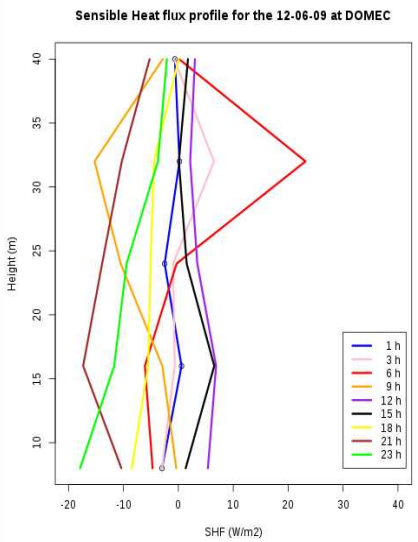
Detailed multi-layer snow model, running in SA mode

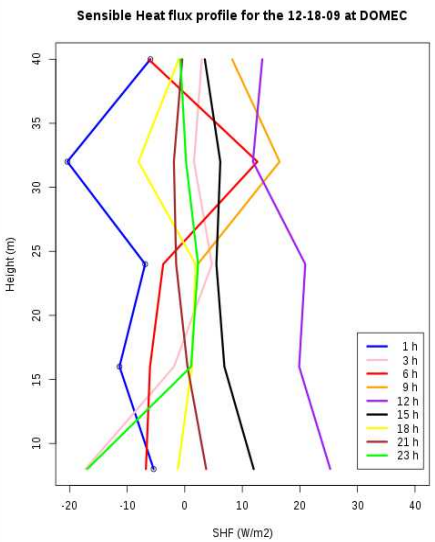


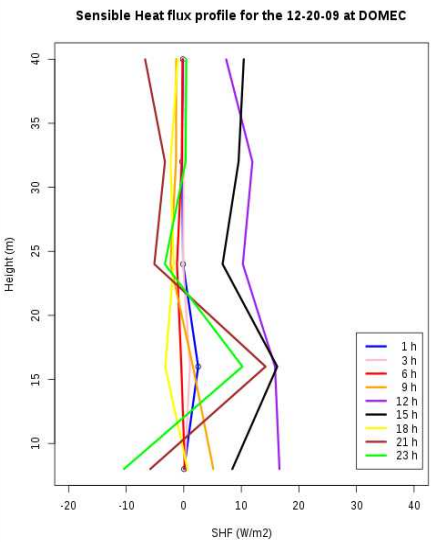
ISBA_ES/CROCUS

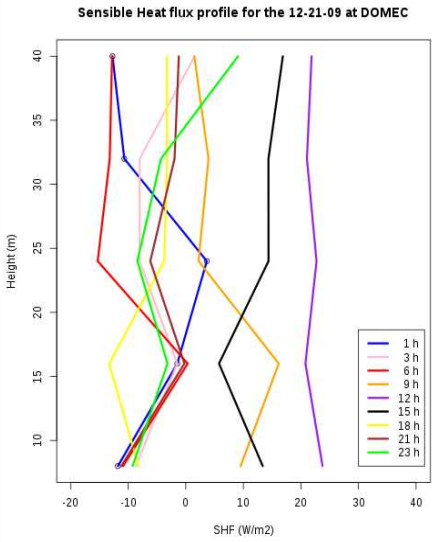
Some sensible heat flux profiles-1

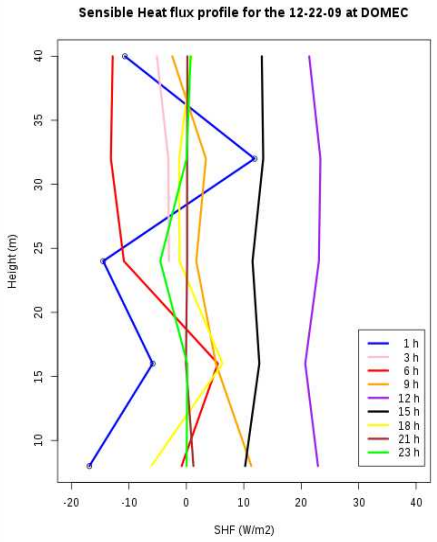


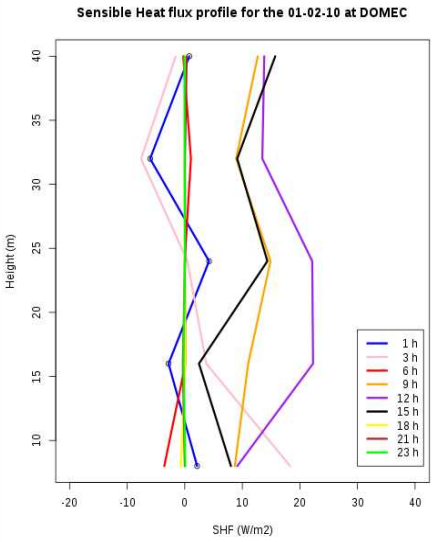


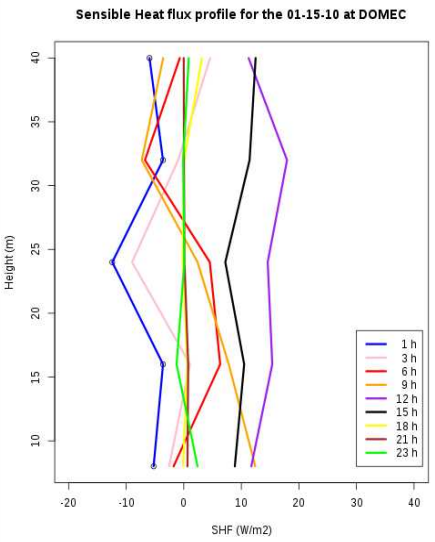




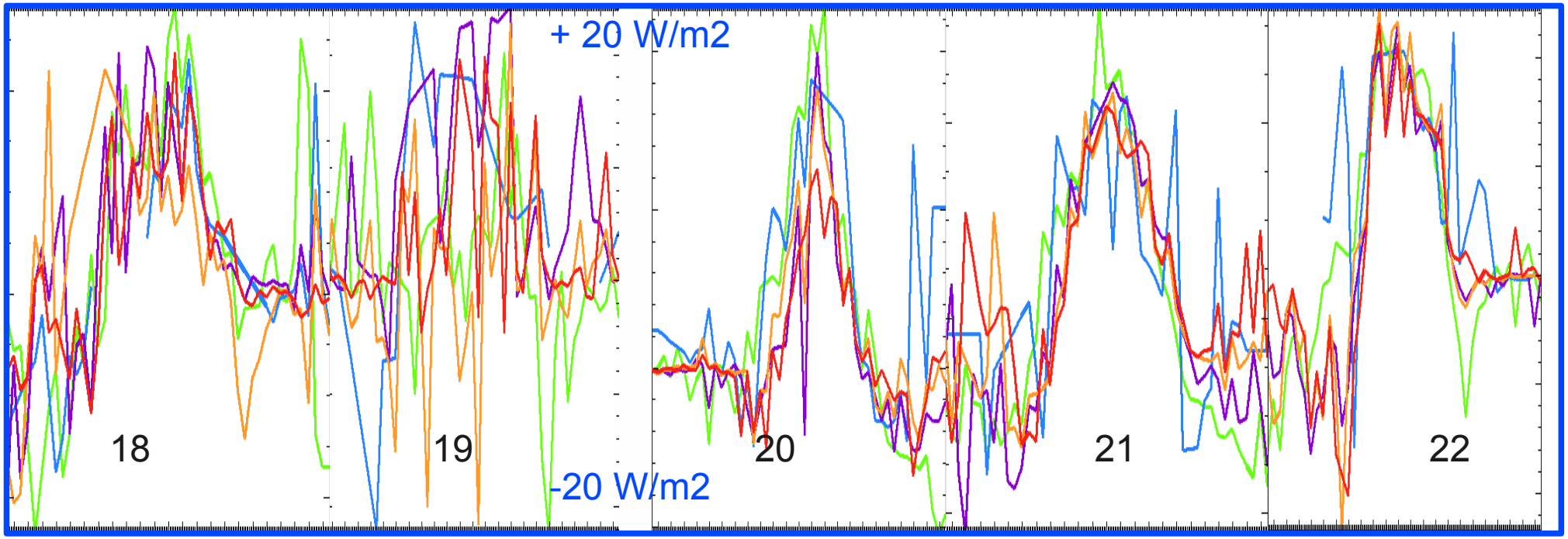








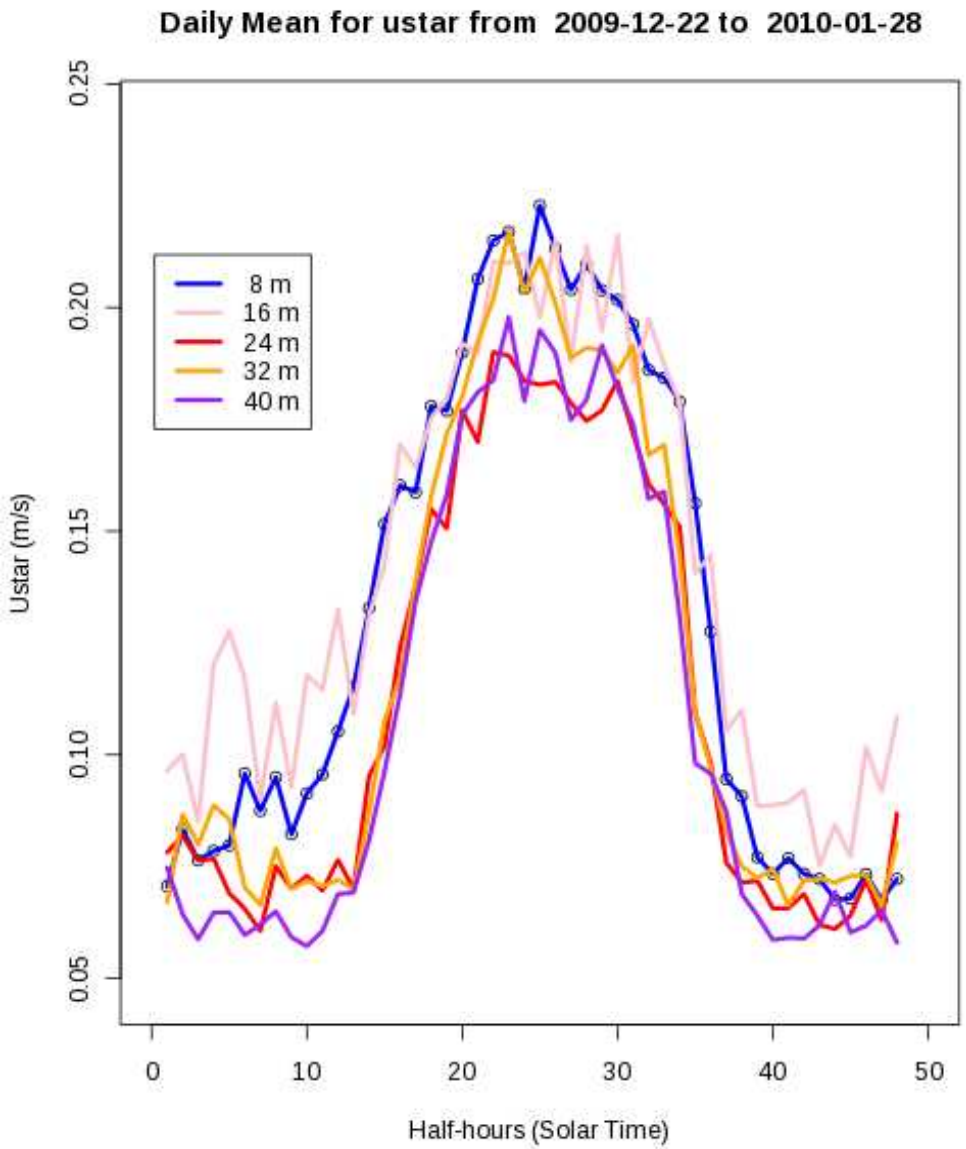
Some sensible heat flux profiles -2

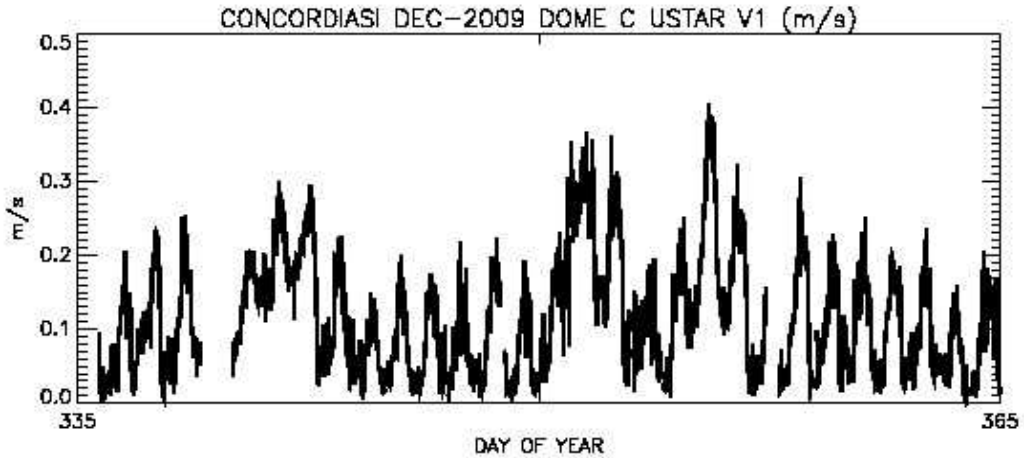


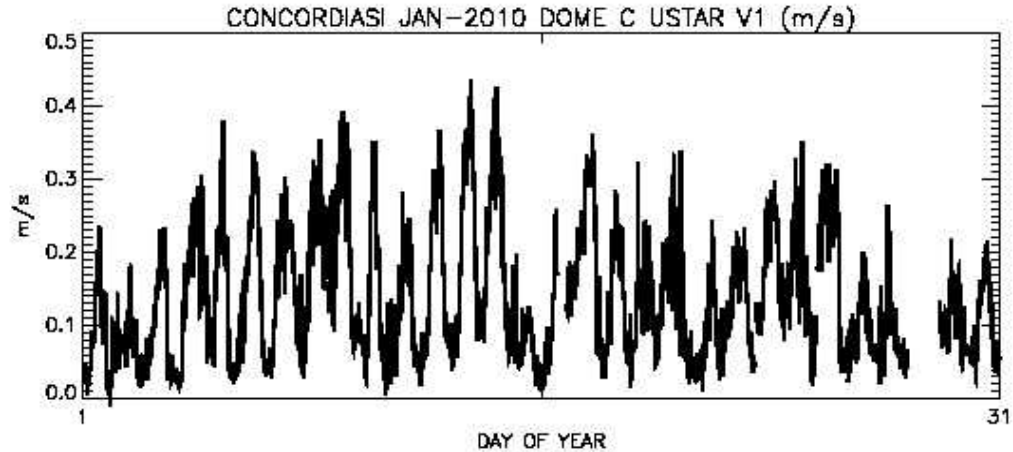
December 2009

1
2
3
4
5

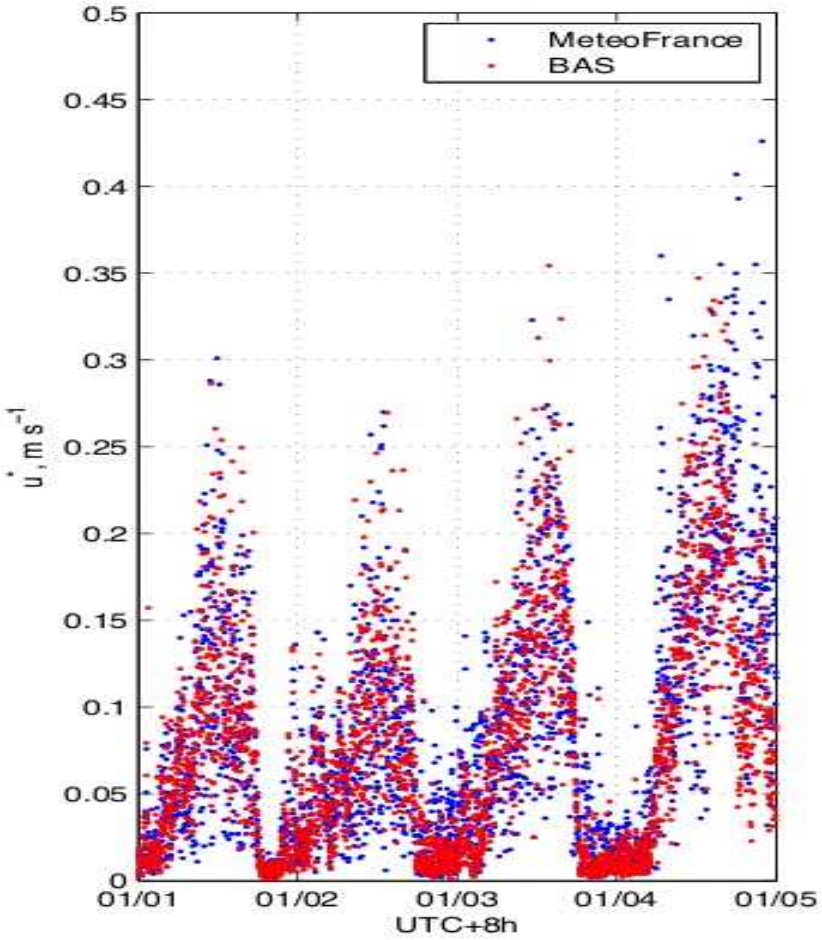
Ustar (tower)
1 month mean : from 12/22/2009 to 01/28/2010

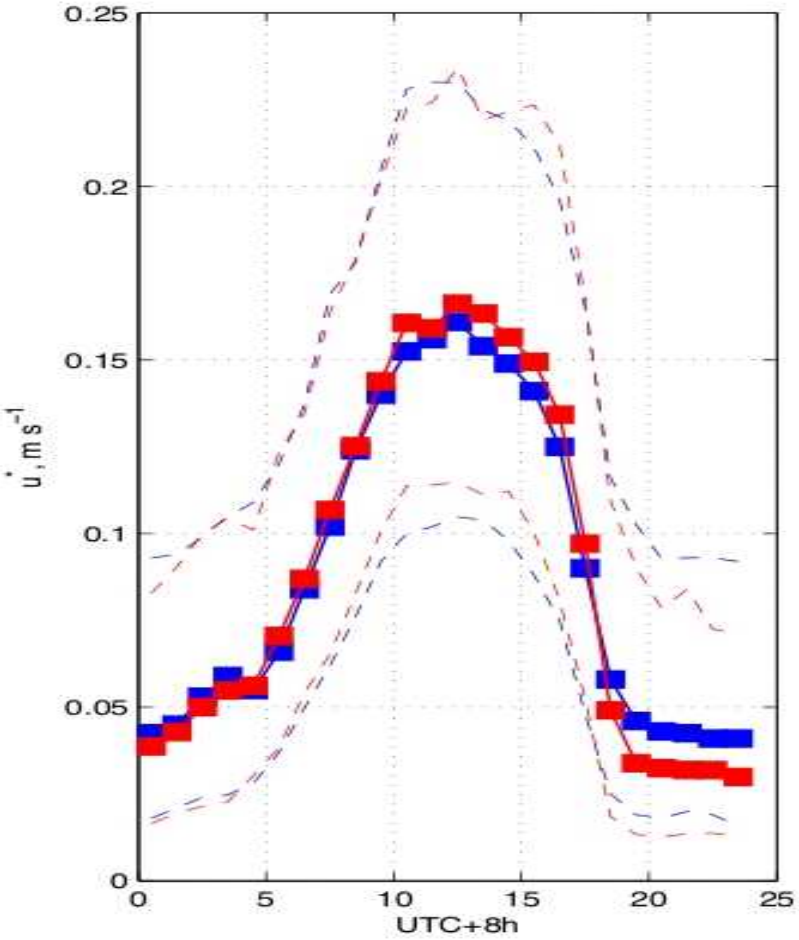






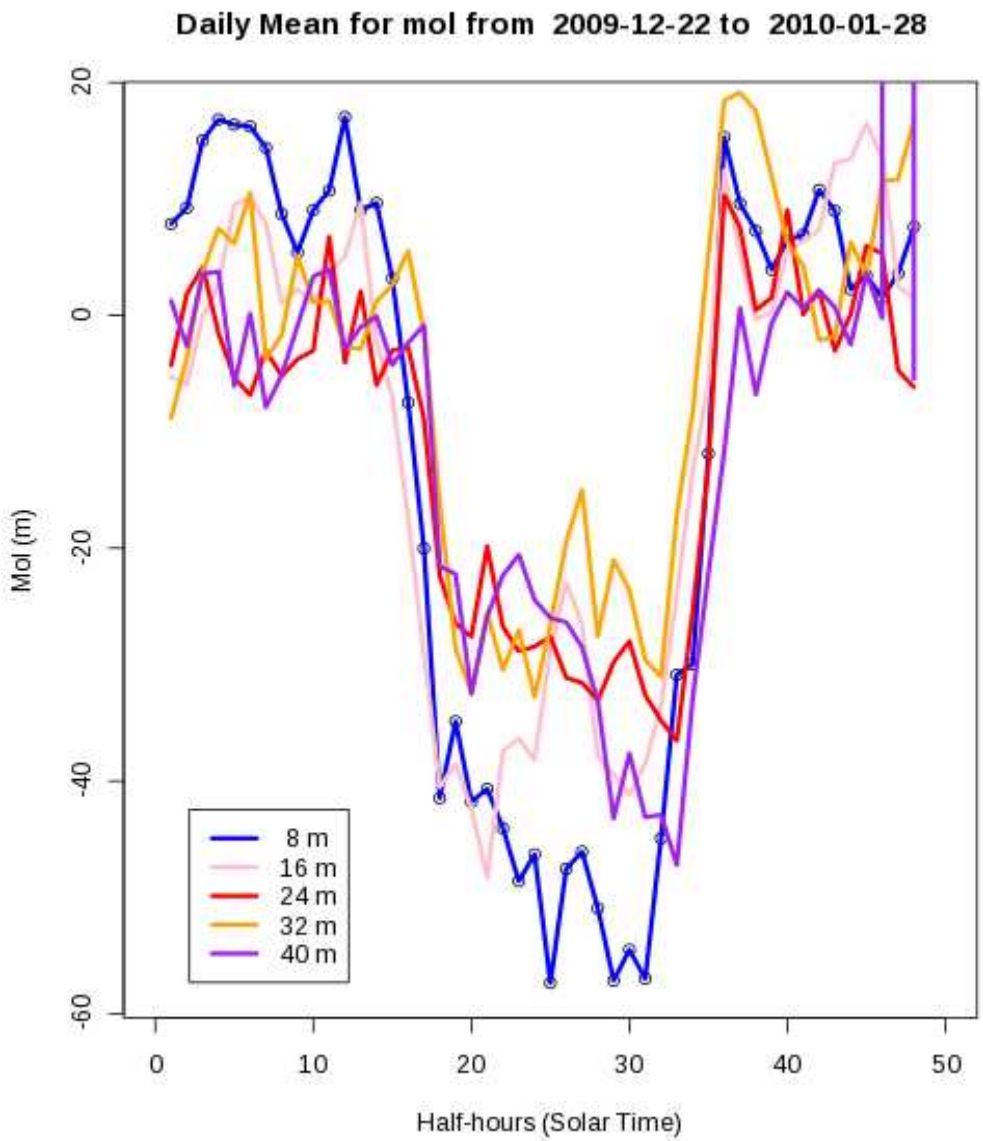
Ustar (tower)
1 month mean : from 12/22/2009 to 01/28/2010

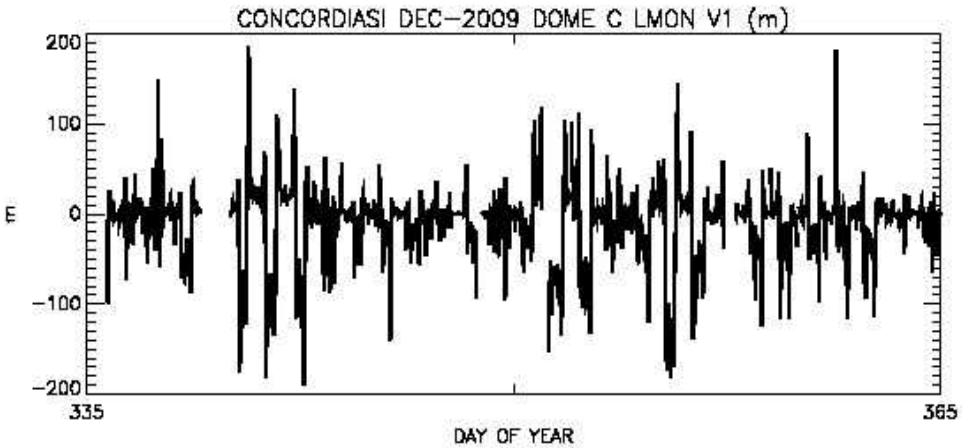


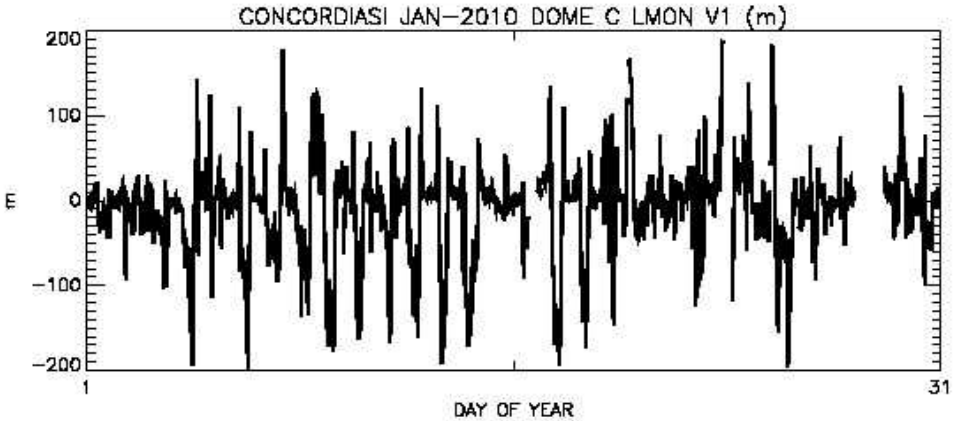


Ustar's comparisons : BAS vs CNRM

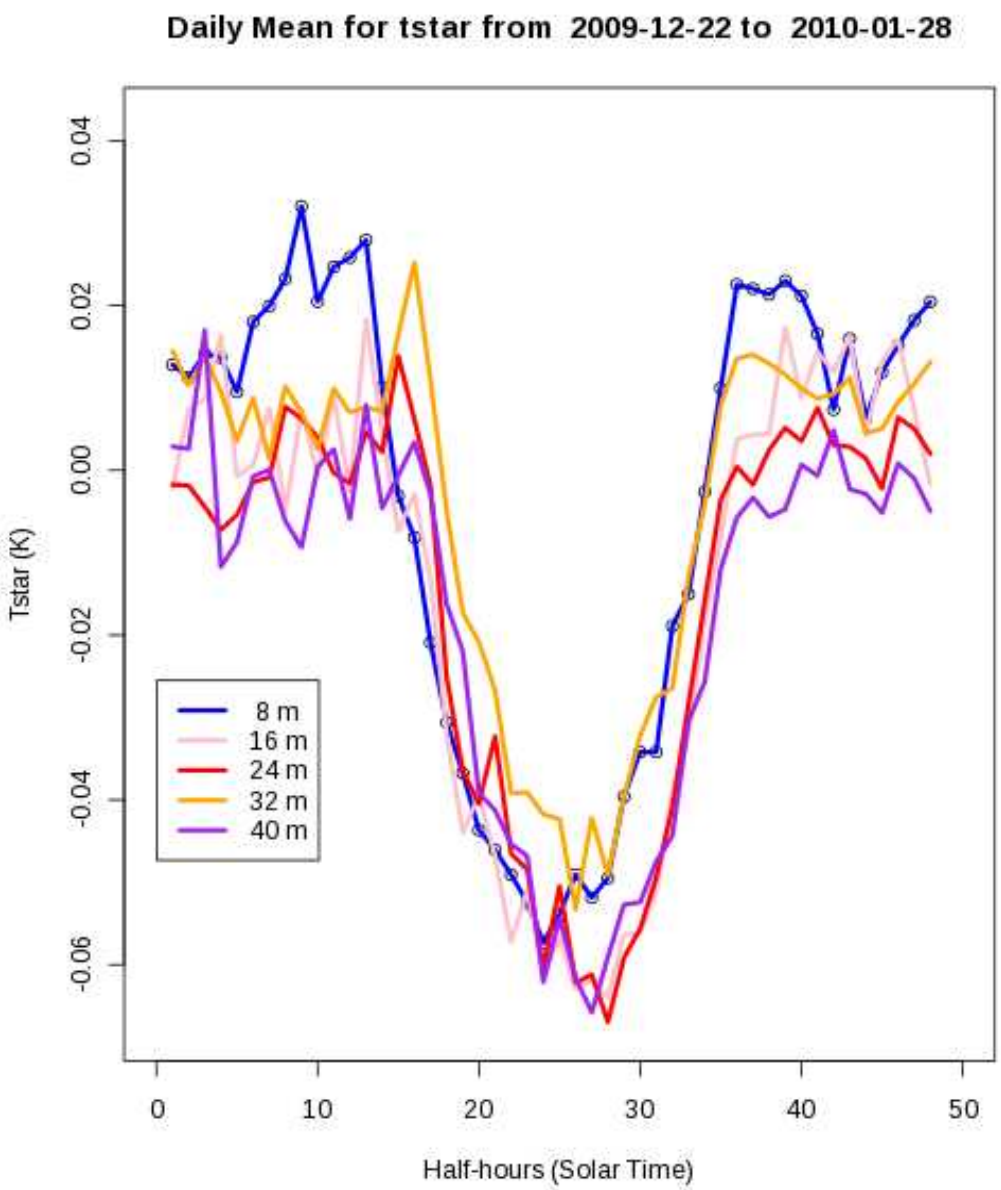
Mol (tower)
1 month mean : from 12/22/2009 to 01/28/2010

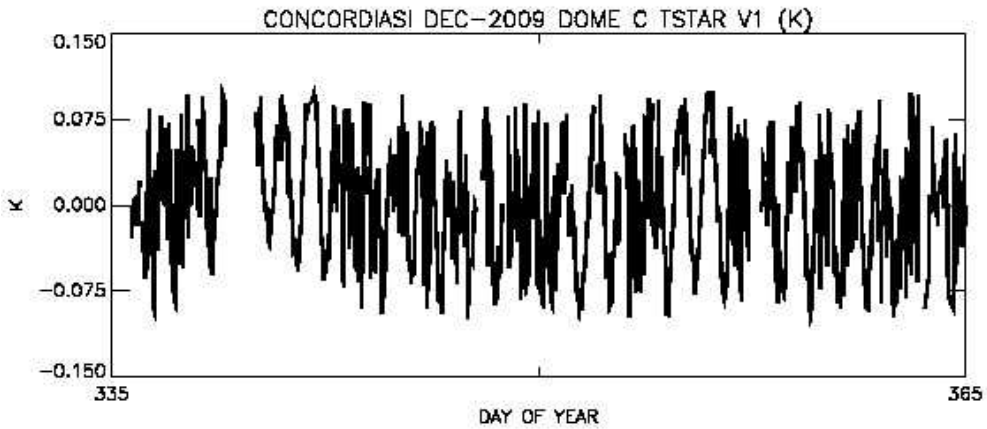


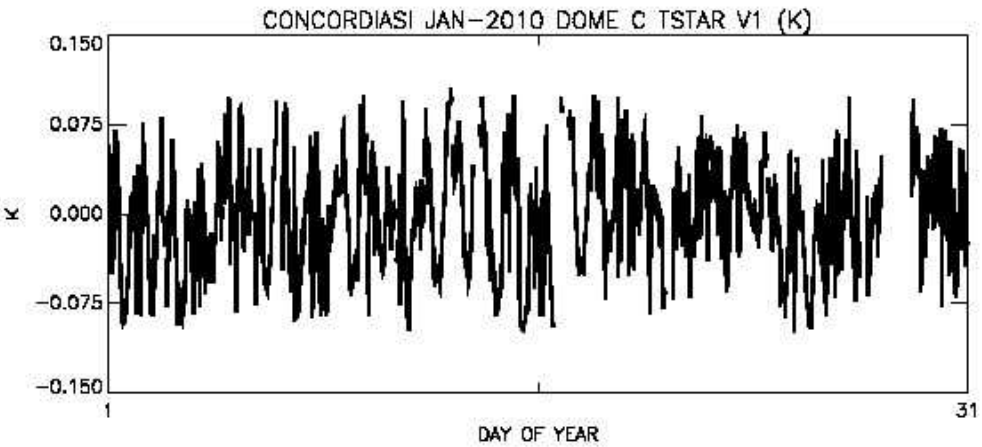




Tstar (tower)
1 month mean : from 12/22/2009 to 01/28/2010

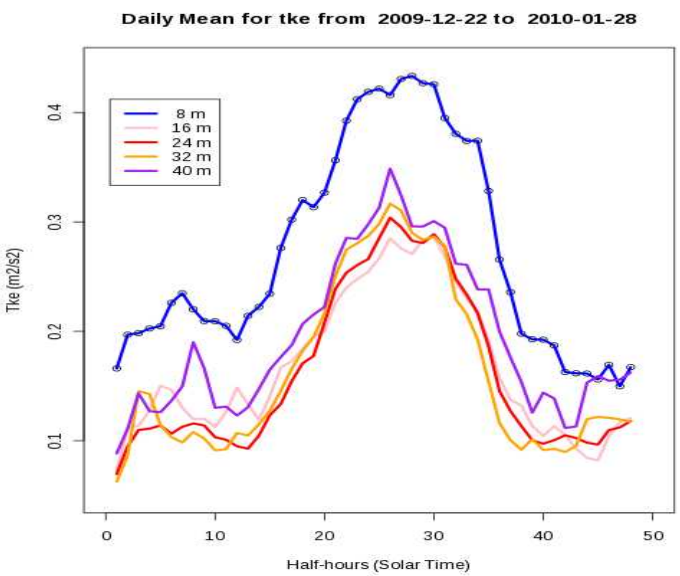




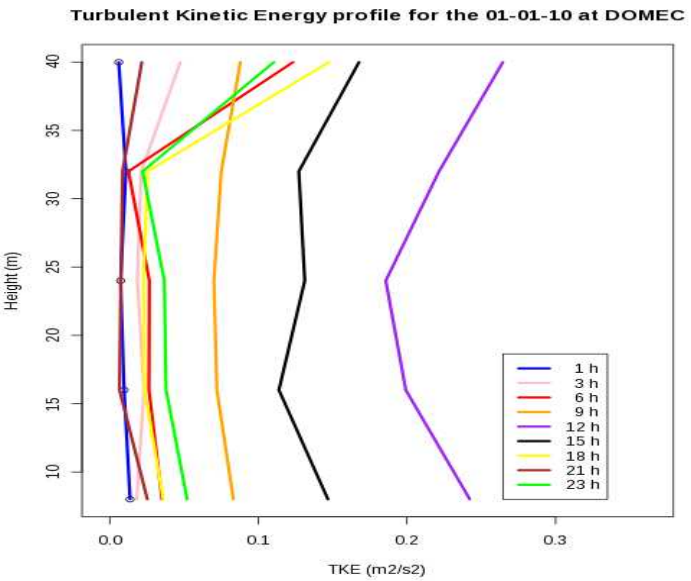


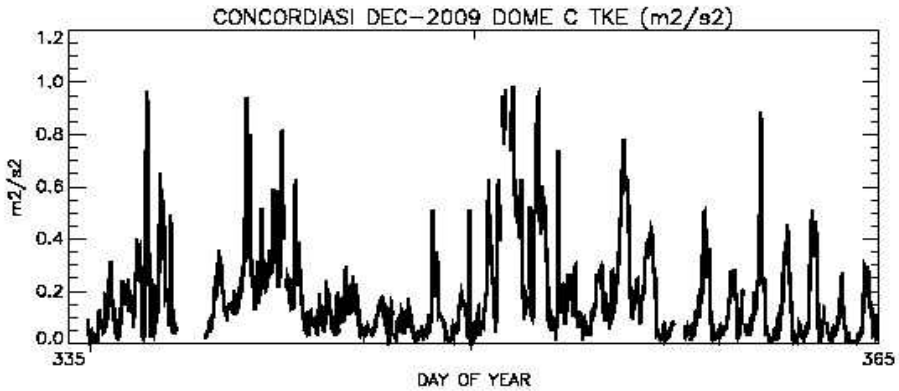
TKE

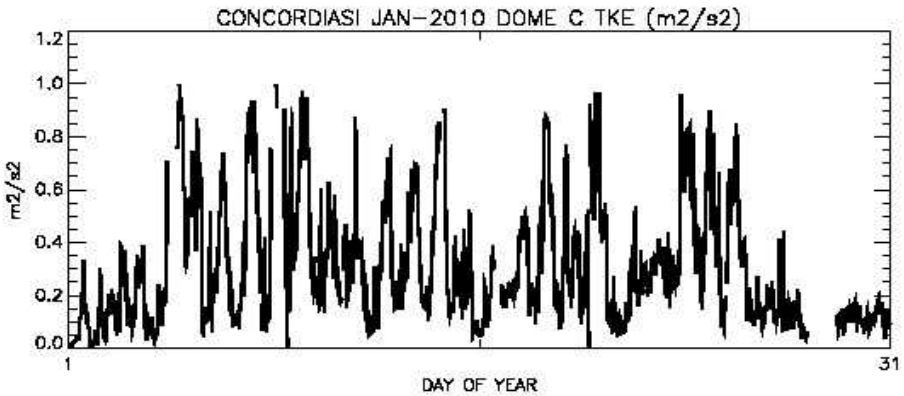
mean from 12/22/2009 to 01/28/2010



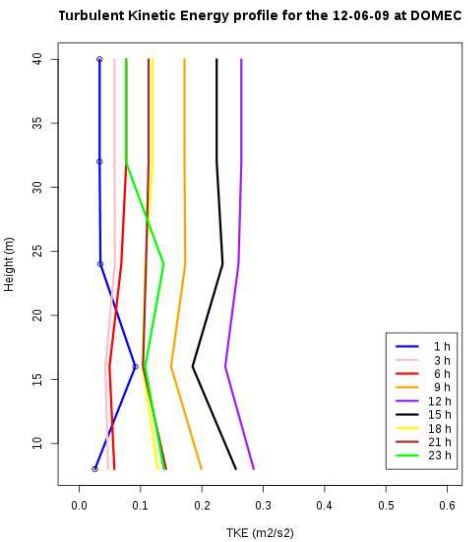
01/01/2010 profile

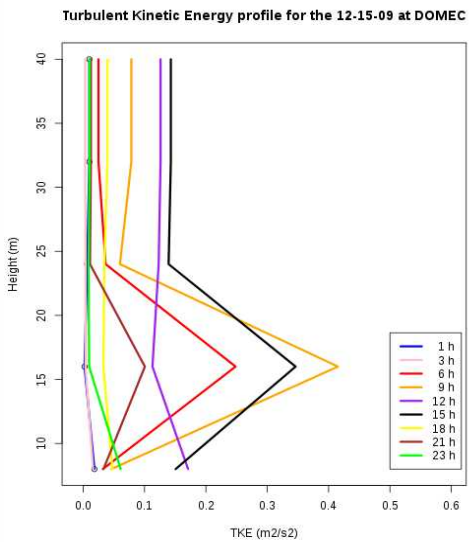


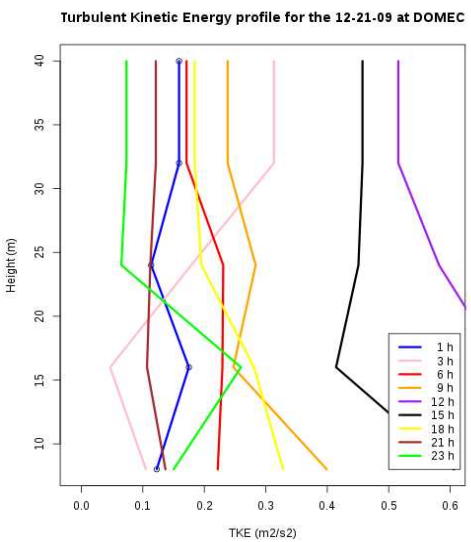


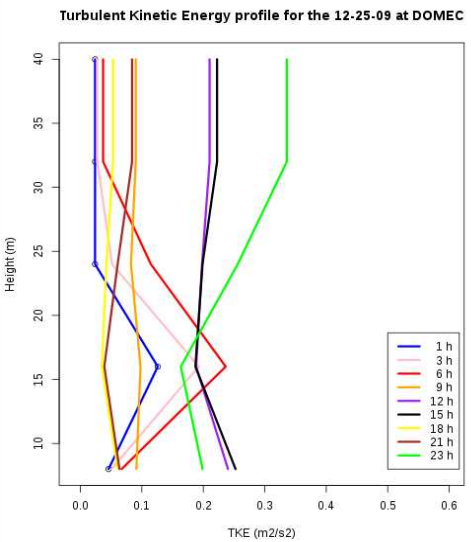


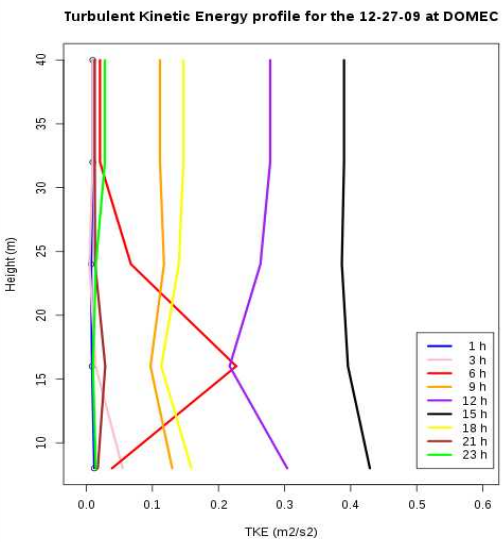
Some TKE profiles

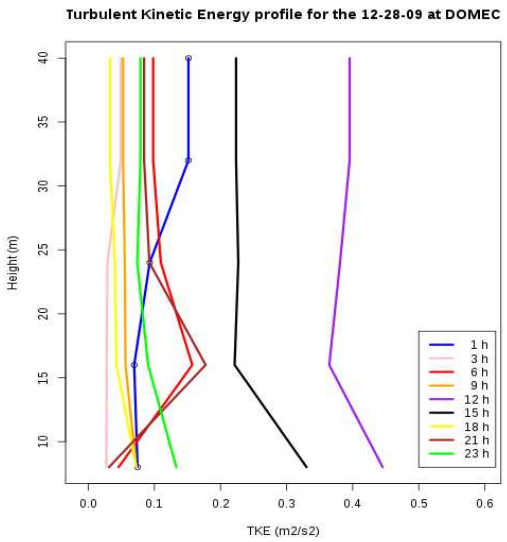


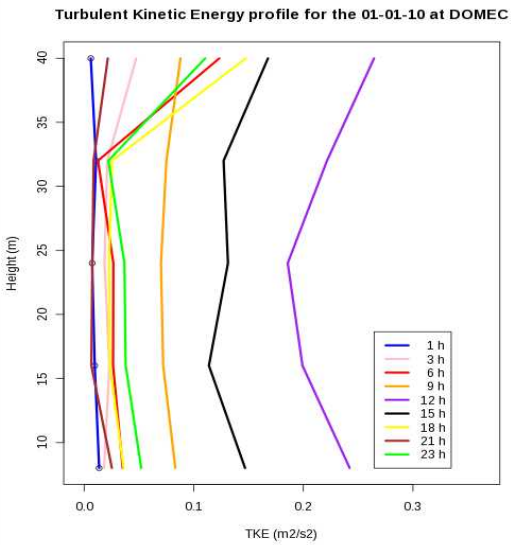




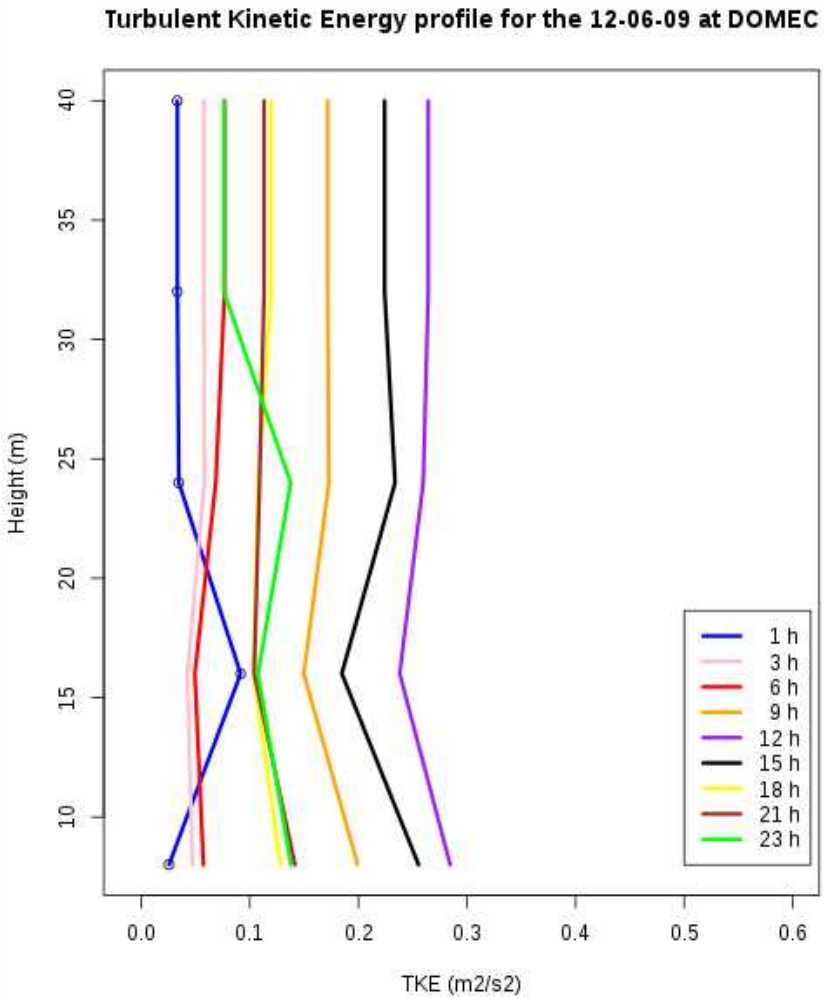


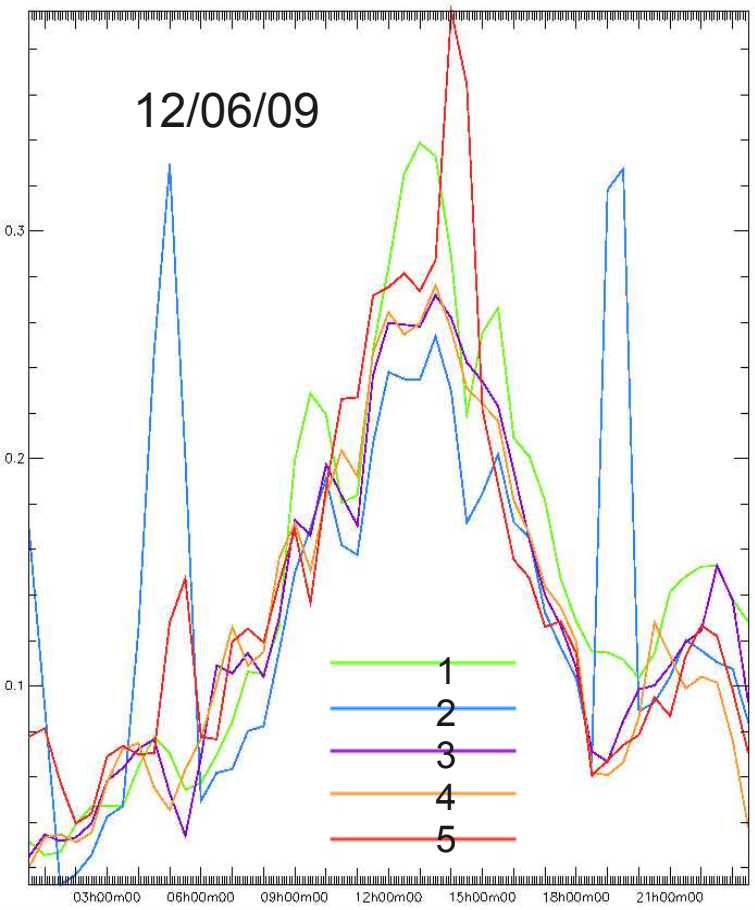




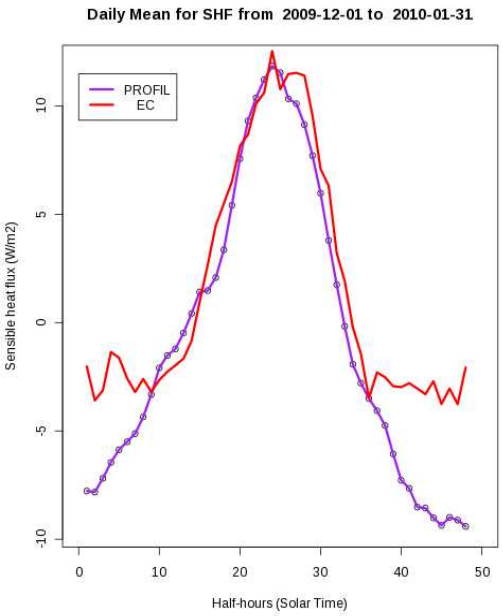


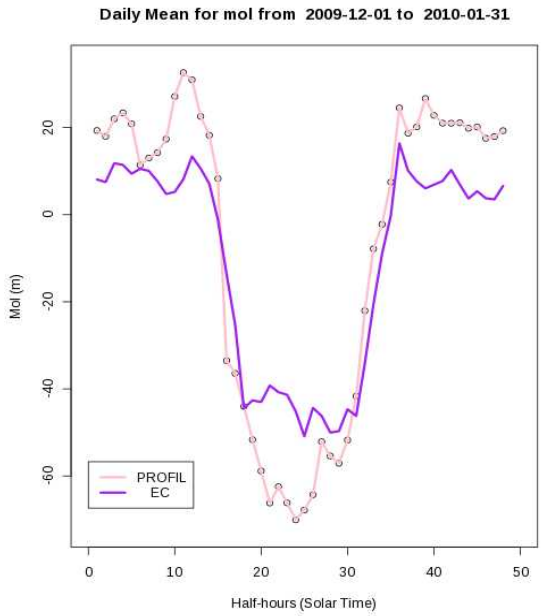
TKE profiles

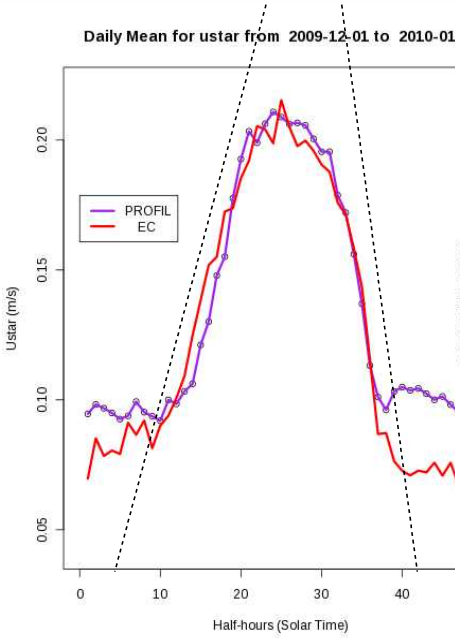


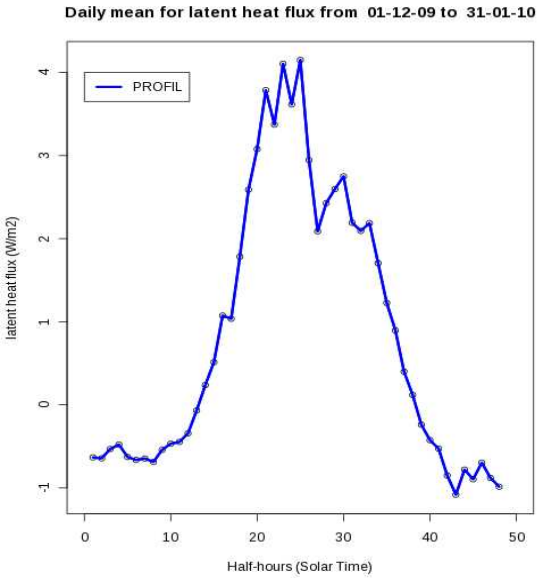


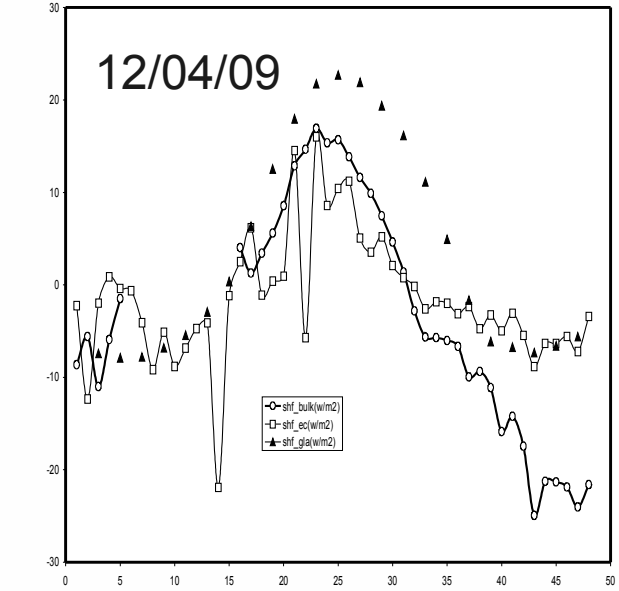
Some comparisons between Profiles and EC method from 12/01/2009 to 01/31/2010

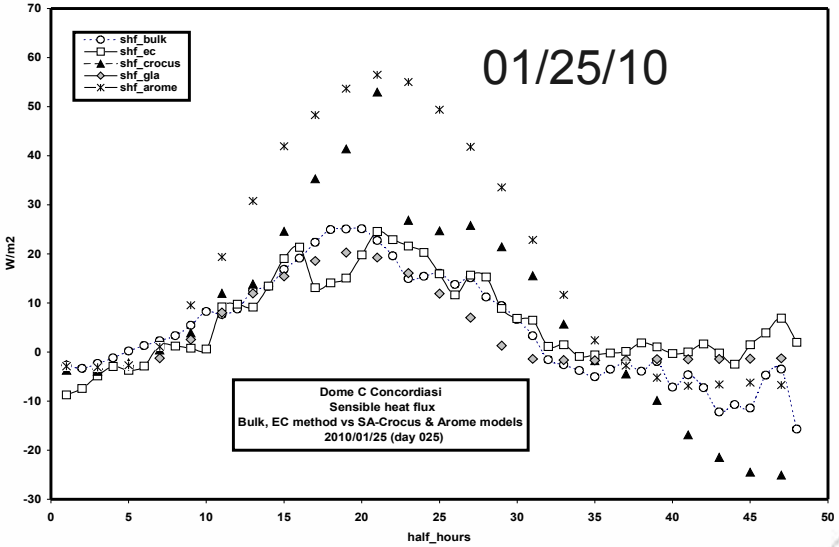




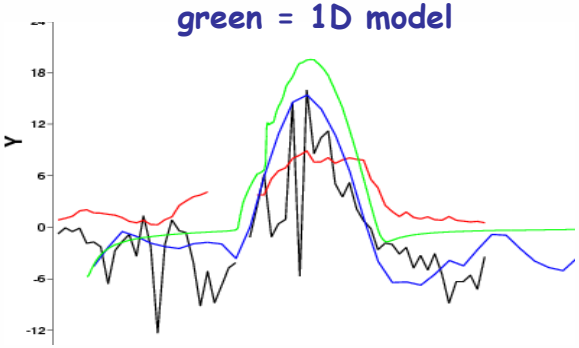






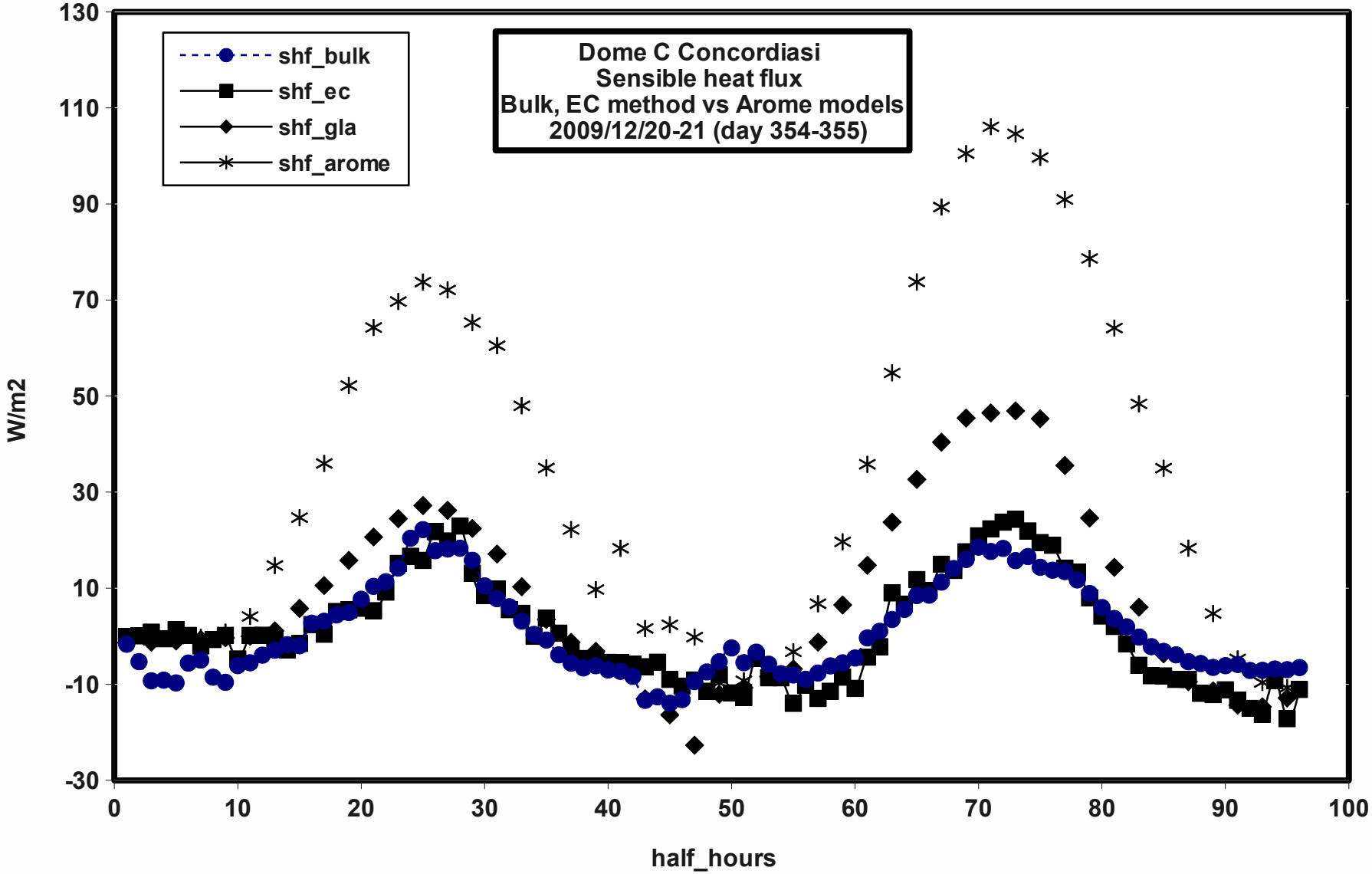


Black = SHF Obs
Red = SHF Obs
Blue = 3D model
green = 1D model

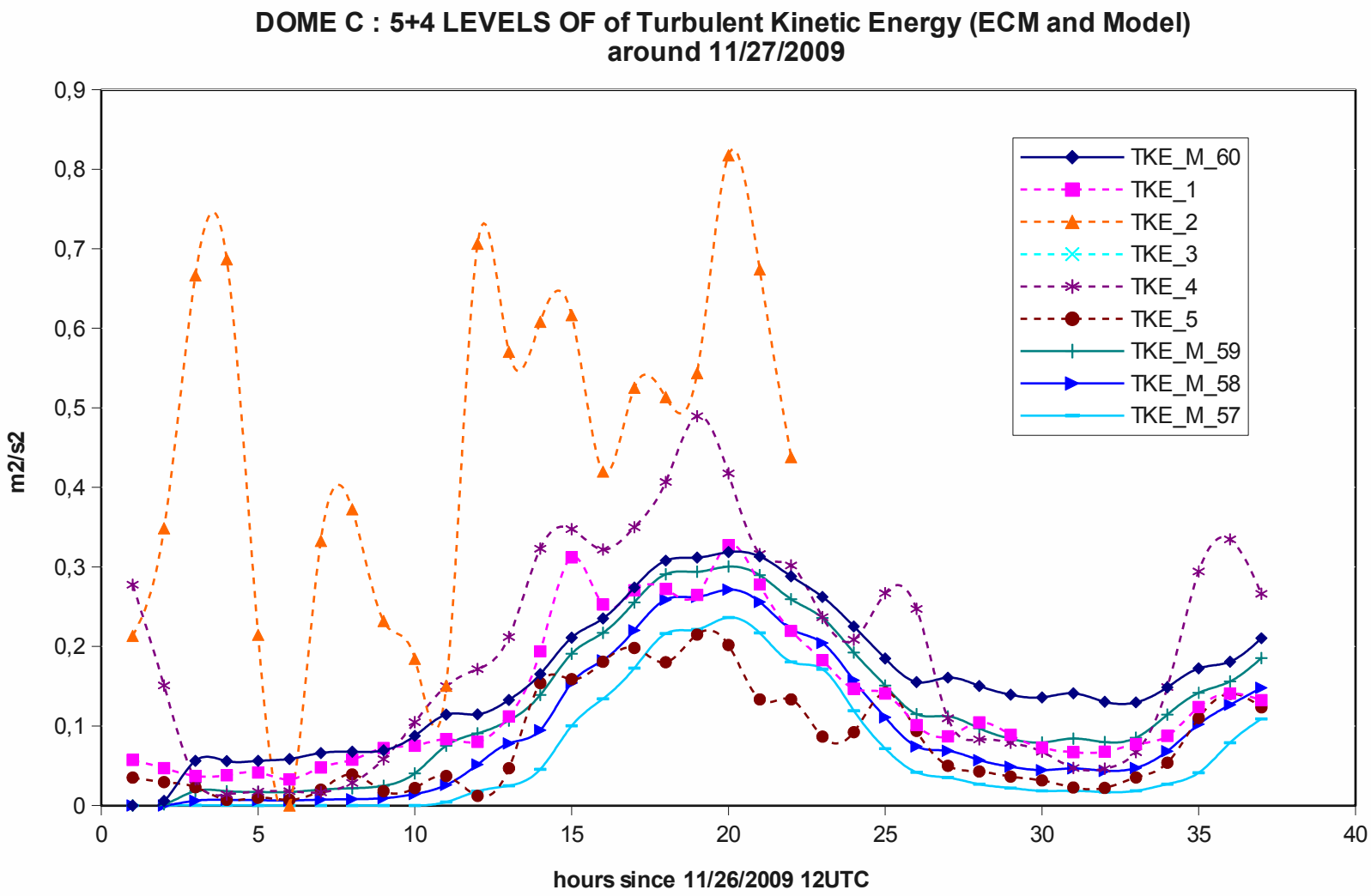


METEO FRANCE
Toujours un temps d'avance

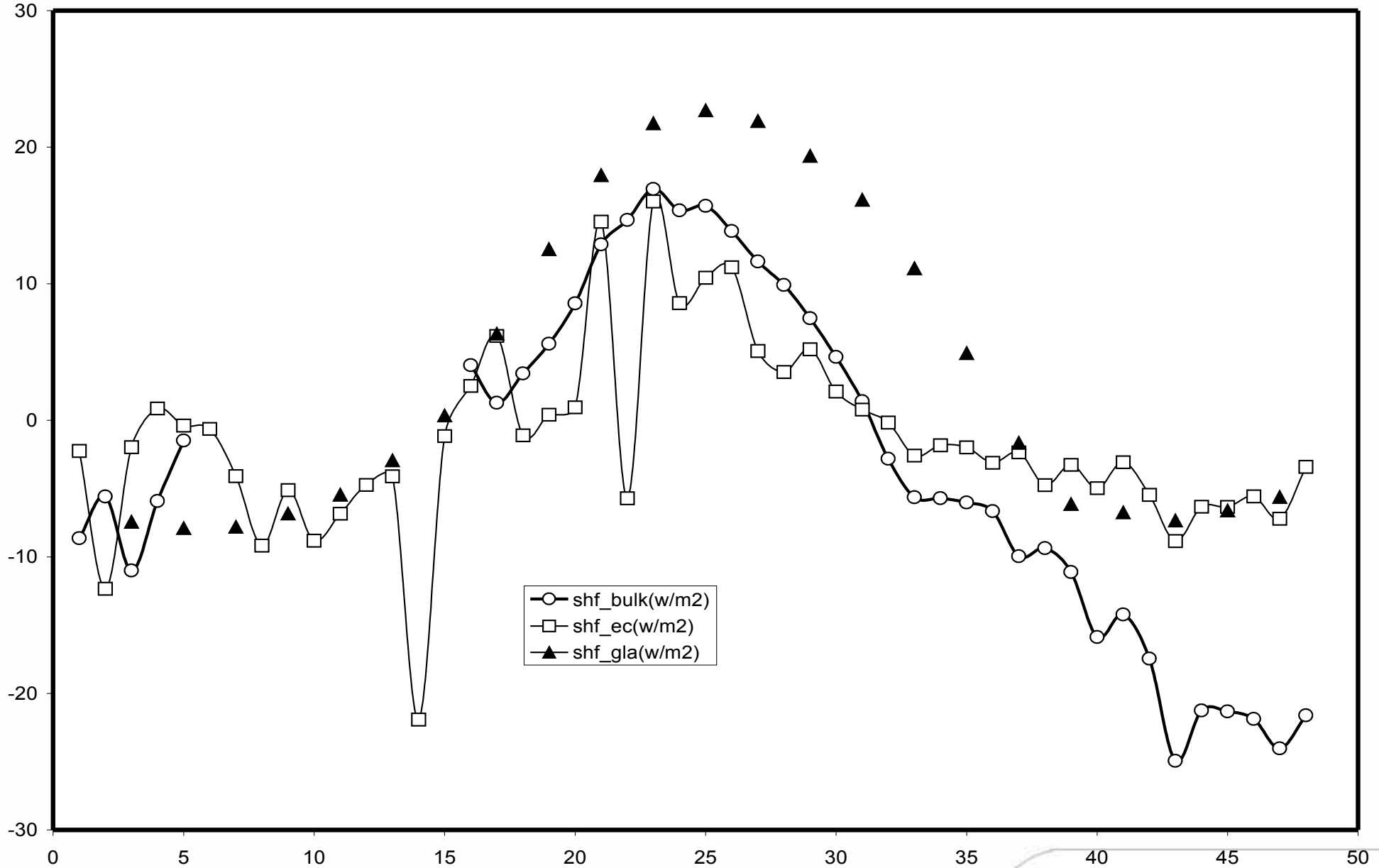
Some comparisons between Models, P and EC method



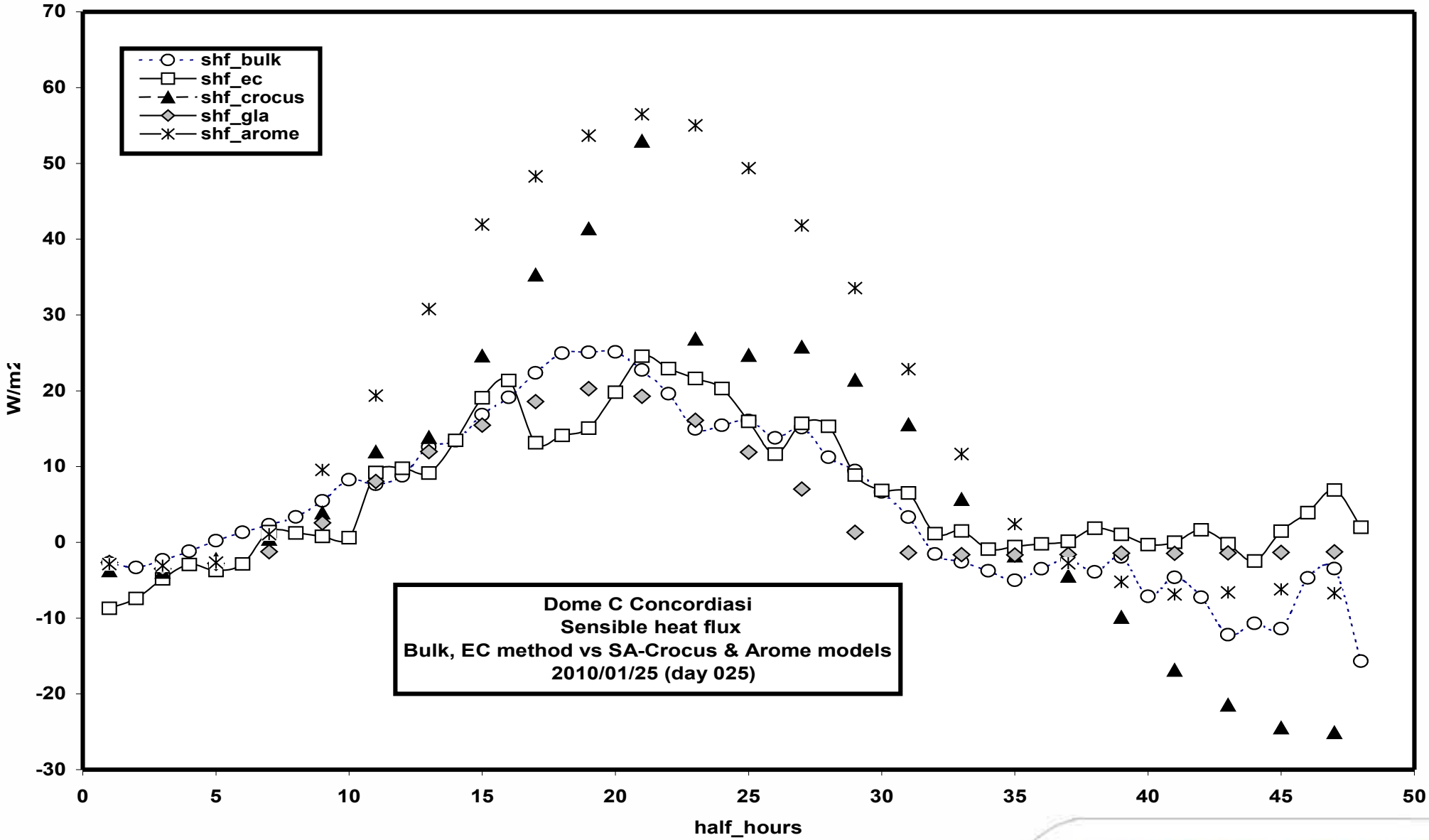
Some comparisons between Models, P and EC method



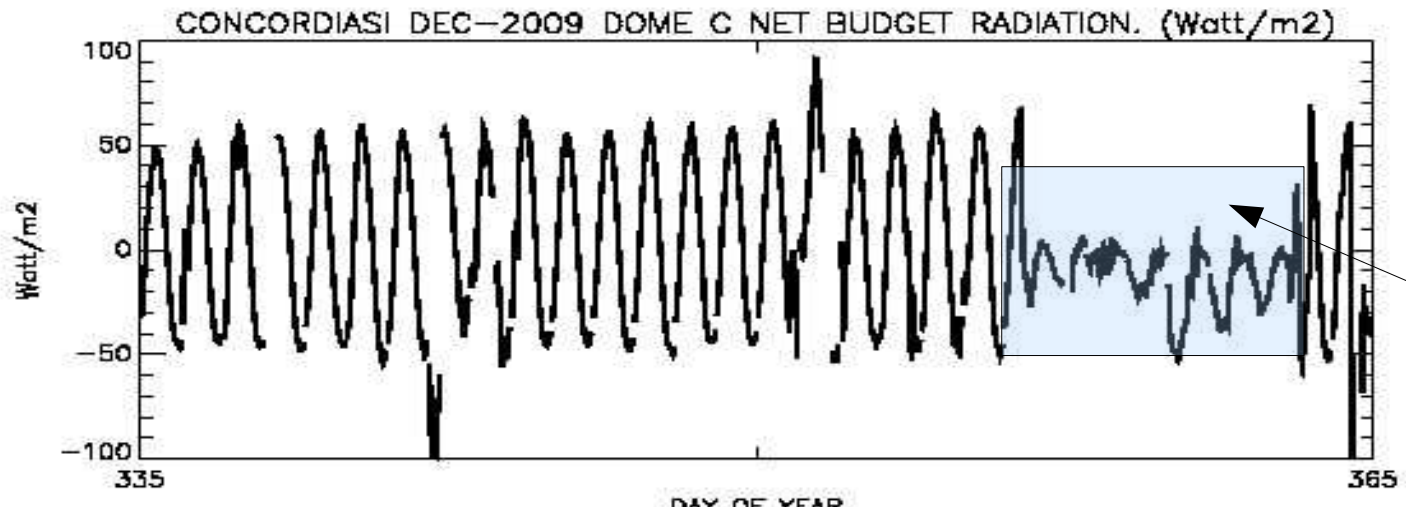
SHF : Models VS Observations (12/04/2009)



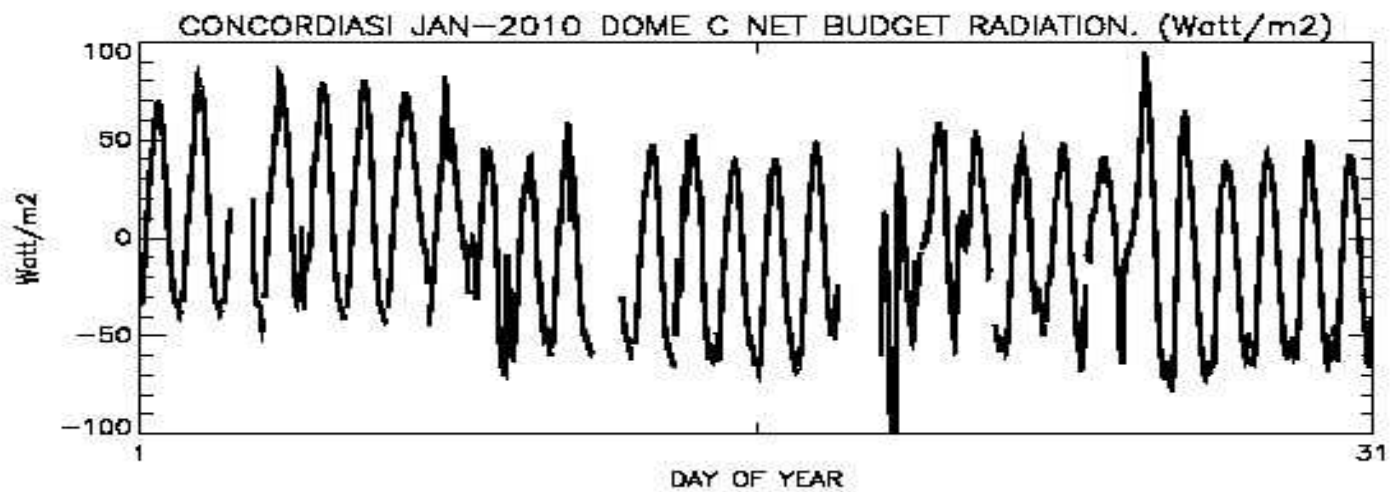
SHF : Models VS Observations (01/25/2010)



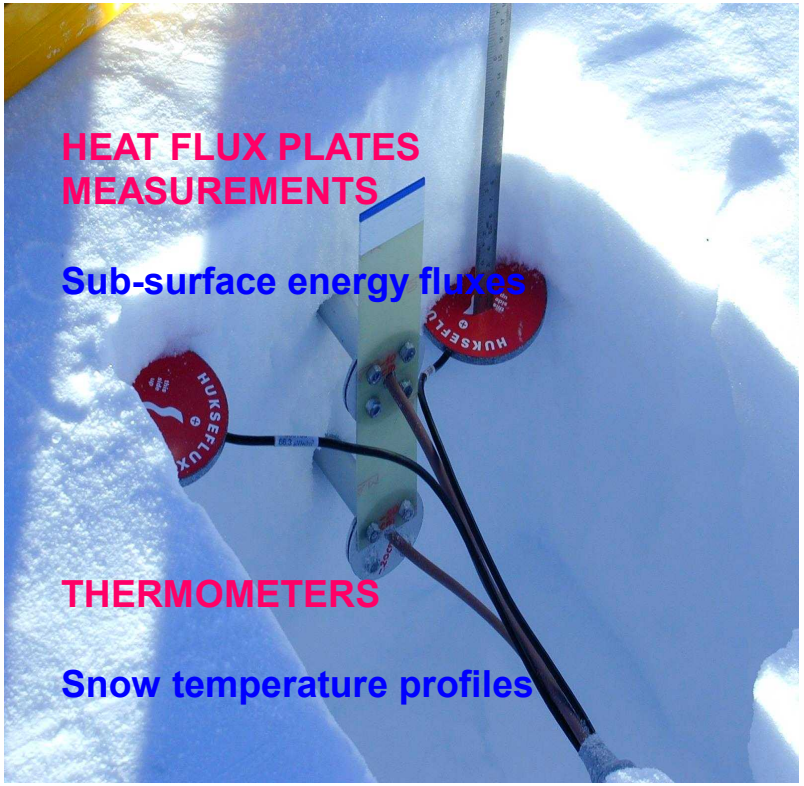
Net Budget Radiation (from BSRN-alba) 12/01/2009 to 01/31/2010



Calibration period



What else to do?

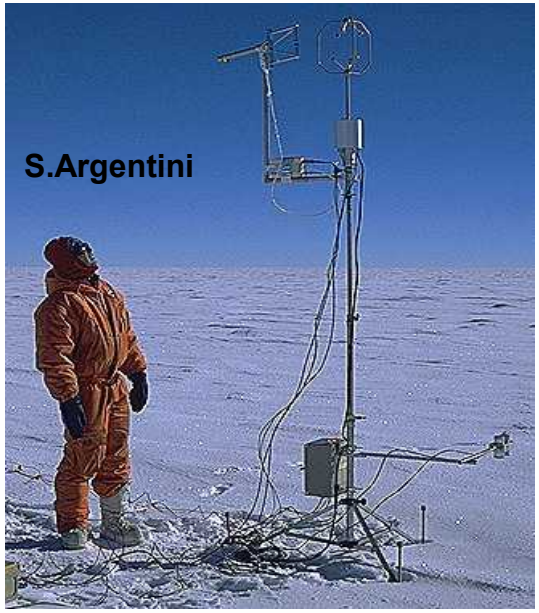


Conventional HFP01 heat flux plates at depth of 0, 5, 15, 30, 50 cm (S.Argentini)

Dome C / Concordia : the site
to study snow-atmosphere interactions :
GABLS 4 : a 1D case to improve 3D models ?

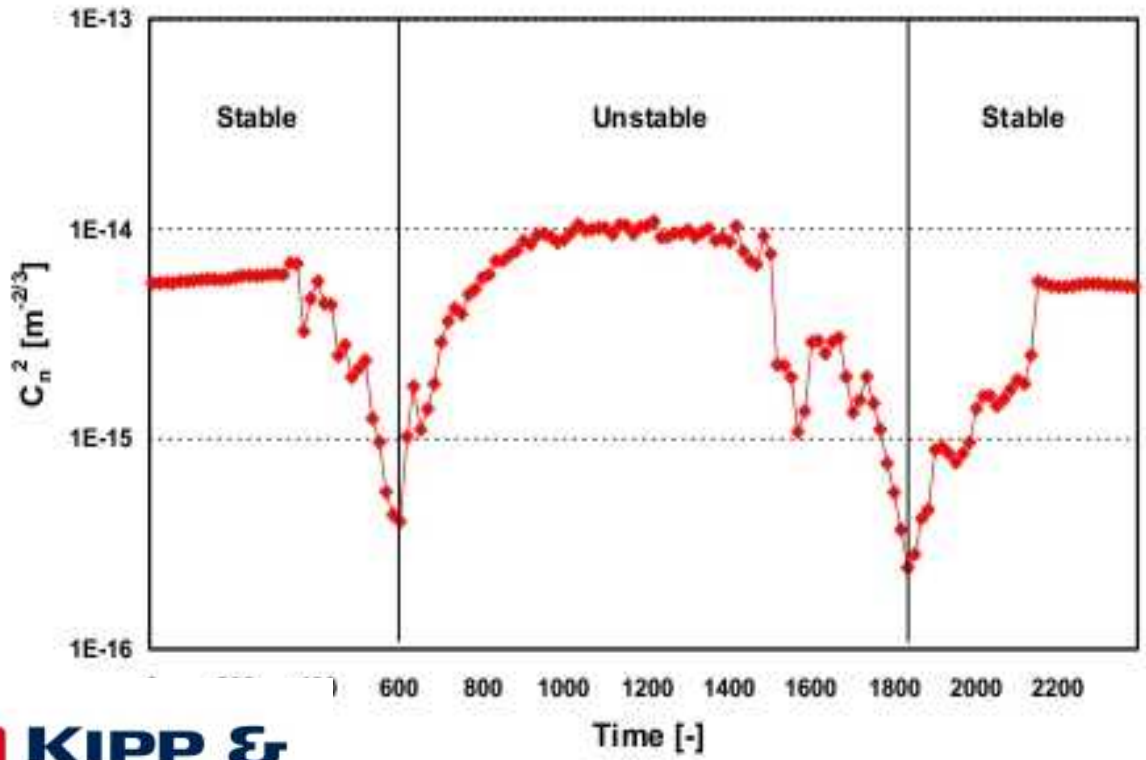
Need of other data and instruments
(for Energy Budget) :

Fast Hygrometers,
Ground Fluxes
measurements,
lidars, sodars, aso..



Scintillation technique : C_N^2 measurements

Example of diurnal cycle of C_N^2 obtained with a LAS for a sunny day (not in Antarctica) ; we distinguish stable and instable conditions between the distinct drops around 6:00 and 18:00

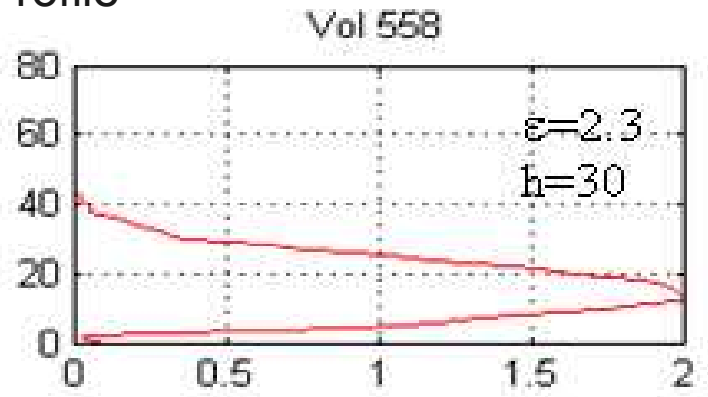


KIPP & ZONEN
SINCE 1830

METEO FRANCE
Toujours un temps d'avance

Scintillation technique : C_N^2 measurements

CN2 Profile



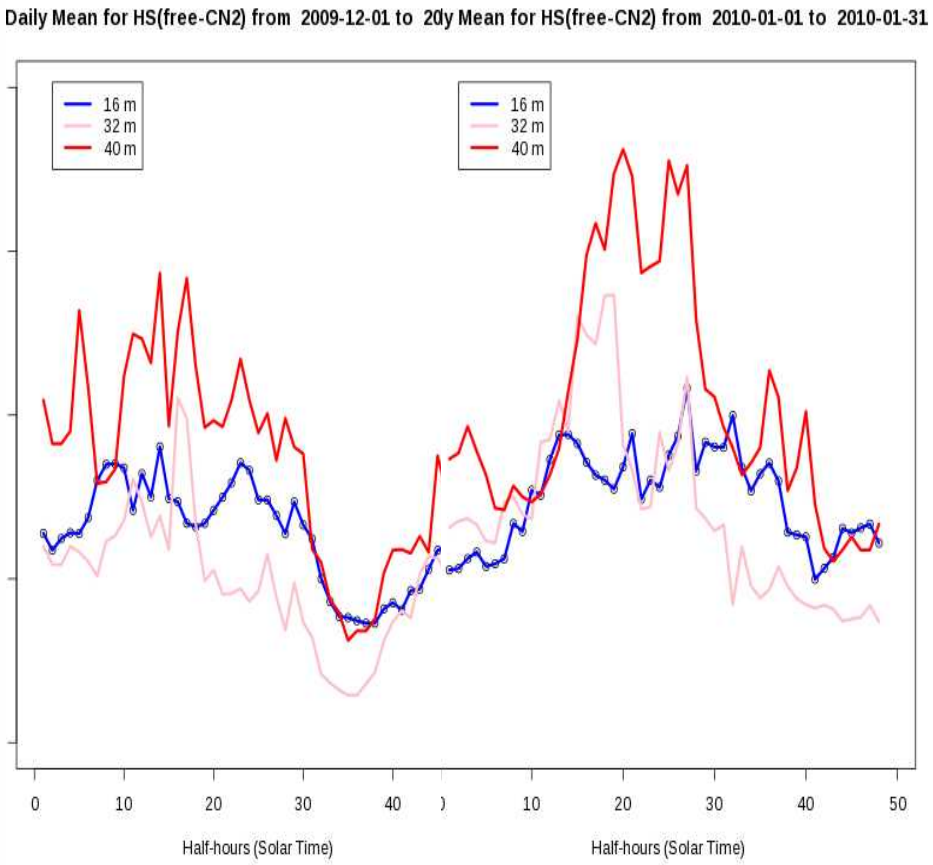
Scintillation technique : Can we deduce sensible heat fluxes from C_N^2 measurements ?

Gladstone Formula :

$C_N^2 = C_T^2 (-0{,}78E\text{-}6)^2 (P/T^2)^2$; if very dry

In case of free convection (and weak u*) :

$Hs(fc)=\rho C_p B(Z-d)(g/T)^{0,5}(C_T^2)^{0,75}$



3 levels SHF (free) : dec. 09, and jan. 10

With the courtesy of :

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Christian Lanconelli (ISAC, Bologna, It)
Andrea Pellegrini (ENEA, Roma, It)
Eric Fossat, and Eric Aristidi (FISEAU, Nice, Fr)
Markus frey (BAS, De)
Stefania Argentini (ISAC, Bol., It)
Thanks to Dr. Thomas Foken (University of Bayreuth) and Dr. EL Andreas
Many thanks to all my MF colleagues and to LGGE.

Preliminary results on turbulent measurements over an instrumented profile tower in Dome C Antarctica

ANY QUESTIONS ?