# Elements

Volume 25, Number 1 January 2007

THE NEWSLETTER OF THE CANADIAN GEOPHYSICAL UNION

**IN THIS ISSUE**



LE BULLETIN DE L'UNION GÉOPHYSIQUE CANADIENNE

## President's Column

The next Annual Meeting of the CGU will be held in St. John's Newfoundland, at the Delta Hotel and St. John's Congress Centre, from May 28 - June 1, 2007 as a joint Congress of the Canadian Meteorological and Oceanographic Society (CMOS), the Canadian Geophysical Union (CGU), three committees of the American Meteorological Society (AMS) and the Eastern Snow Conference (ESC). The three AMS Committees taking part are: Polar Meteorology and Oceanography; Climate Variability and Change; and Air-Sea Interaction. This promises to be an exciting meeting which will promote the combined scientific interests of the CGU, CMOS, AMS and ESC. Most of the fields of a typical AGU meeting will be covered in this meeting, although it will be a smaller and more intimate meeting. The Call for Papers and other details can be found in this issue of *Elements*, on pages 16-17. Information can also be found on the web site http://www.cmos2007.ca. Because air travel to St. John's is relatively expensive, the Executive Committee has voted to double the budget for student travel awards from a total of $5,000 to a total of $10,000 on a one-time-only basis for the 2007 meeting. If the meeting is as successful as we hope, the 2007 joint congress may be the prelude to regularly scheduled joint CGU-CMOS meetings once every few years.

The CGU program includes geophysics sessions on glaciers and ice sheets, the thermal state, structure and dynamics of the Earth's interior, monitoring the deformation of the Earth's surface, terrestrial and oceanographic datums, geomagnetism, near-surface geophysics, crustal seismology, advances in geophysical techniques, and petroleum exploration and production geophysics in the Atlantic, and hydrology sessions on isotope tracing, watershed experiments, prediction in ungauged basins, and stream processes. There will also be a significant number of interdisciplinary sessions, as well as sessions on climate, the oceans and atmosphere, snow, and of course plenary sessions.

The 2008 CGU meeting will be held in Banff, Alberta again, at the Banff Park Lodge, a relatively upscale hotel and conference facility. While rooms will be available to conference registrants at very favourable rates, the main advantage for the CGU is that the use of, and charges for, conference facilities are not tied to guarantees of accommodation bookings. Thus our costs will be the same whether conference attendees stay at the conference hotel or elsewhere in Banff. The CGU Executive Committee believes this arrangement is best when the CGU meets alone or with another small society. In 2008 we will be joined by about 50 members of the Canadian Geomorphology Research Group (CGRG).

We welcome your views on any topics related to the activities, plans and strategies for the CGU. Please send your comments to any member of the CGU Executive Committee, as listed on the last page of this newsletter. Thank you for your contributions.

Ed Krebes, Editor, for Gary T. Jarvis, President

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## J. Tuzo Wilson Medal – Call for Nominations

The Executive of the CGU solicits nominations for the J. Tuzo Wilson Medal – 2007. The Union makes this award annually to recognize outstanding contributions to Canadian geophysics. Factors taken into account in the selection process include excellence in scientific and/or technological research, instrument development, industrial applications and/or teaching.

If you would like to nominate a candidate, please contact Dr. Hugh Geiger, Chair of the CGU Awards Committee, Geology and Geophysics Dept., University of Calgary, Calgary AB, T2N 1N4 (Email: geiger@ucalgary.ca, Fax: 403-284-0074). At a minimum, the nomination should be supported by letters of recommendation from colleagues, a brief biographical sketch and a Curriculum Vitae. Nominations should be submitted by February 28, 2007. Additional details concerning the nomination process can be obtained from the Chair of the CGU Awards Committee.

L'exécutif de l'UGC vous invite à suggérer des candidats pour la médaille J. Tuzo Wilson – 2007. L'Union décerne la médaille chaque année "en reconnaissance d'une contribution remarquable à la géophysique canadienne". En choisissant parmi les candidats, on considére les accomplissements en recherches scientifique ou technologiques, aux développements d'instruments, aux applications industrielles et/ou à l'enseignement.

Si vous désirez suggérer un candidat pour cette médaille, s.v.p. contacter Dr. Hugh Geiger, Président du Comité des Prix d'Excellence, Geology and Geophysics Dept., University of Calgary, Calgary AB, T2N 1N4 (Email: geiger@ucalgary.ca, Fax: 403-284-0074). Les nominations doivent être supportées de lettres de recommandation de colléques, d'un bref sommaire biographique et d'un Curriculum Vitae. Les nominations doivent être soumises avant le 28 février, 2007. Des détails additionnels concernant le processus de nomination peuvent être obtenus en communiquant avec le Président du Comité des Prix d'Excellence de l'UGC.

***Past Wilson Medallists***

| | |
|---|---|
| 1978 | J. Tuzo Wilson |
| 1979 | Roy O. Lindseth |
| 1980 | Larry W. Morley |
| 1981 | George D. Garland |
| 1982 | Jack A. Jacobs |
| 1983 | D. Ian Gough |
| 1984 | Ted Irving |
| 1985 | Harold O. Seigel |
| 1986 | Michael Rochester |
| 1987 | David Strangway |
| 1988 | Ernie Kanasewich |
| 1989 | Leonard S. Collett |
| 1990 | Gordon F. West |
| 1991 | Thomas Krogh |
| 1992 | R. Don Russell |
| 1993 | Alan E. Beck |
| 1994 | Michael J. Berry |
| 1995 | Charlotte Keen |
| 1996 | Petr Vaníček |
| 1997 | Chris Beaumont |
| 1998 | Ron M. Clowes |
| 1999 | David Dunlop |
| 2000 | Don Gray |
| 2001 | Roy Hyndman |
| 2002 | Doug Smylie |
| 2003 | Garry K.C. Clarke |
| 2004 | W.R. (Dick) Peltier |
| 2005 | Ted Evans |
| 2006 | Alan Jones |

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## CGU Young Scientist Award – Call for Nominations

The Executive of the CGU solicits nominations for the CGU Young Scientist Award – 2007. The CGU Young Scientist Awards recognize outstanding research contributions by young scientists who are members of the CGU. Both the quality and impact of research are considered. To be eligible for the award, the recipient must be within 10 years of obtaining their first Ph.D. or equivalent degree. The awards are made by the CGU Executive on the recommendations of a special committee struck for this purpose. The selection committee seeks formal written nominations from the membership, plus letters of support and a current curriculum vitae. Nominations for the CGU Young Scientist Awards may be submitted by CGU members at any time.

If you would like to nominate a candidate, please contact Dr. Hugh Geiger, Chair of the CGU Awards Committee, Geology and Geophysics Dept., University of Calgary, Calgary AB, T2N 1N4 (Email: geiger@ucalgary.ca, Fax: 403-284-0074). The nomination should be supported by three letters of recommendation from colleagues. Nominations should be submitted by February 28, 2007. Additional details concerning the nomination process can be obtained from the Chair of the CGU Awards Committee.

L'exécutif de l'UGC vous invite à suggérer des candidats pour le prix pour Jeune Scientifique de l'UGC – 2007. Les Prix pour Jeunes Scientifiques de l'UGC reconnaissent les contributions exceptionnelles de jeunes scientifiques qui sont membres de l'UGC. La qualité et l'impact de la recherche sont considérés. Pour être éligible pour le prix, le scientifique doit avoir obtenu son premier Ph.D. ou degré équivalent au cours des dix dernières années. Les prix sont accordés par l'Exécutif de l'UGC sur recommendations d'un comité spécial à cette fin. Le comité de sélection sollicite des nominations formelles par écrit des membres de l'UGC, accompagnées de lettres d'appui et d'un curriculum vitae à jour. Des nominations pour les Prix pour Jeunes Scientifiques de l'UGC peuvent être soumis en tout temps par les membres de l'UGC.

Si vous désirez suggérer un candidat pour cette médaille, s.v.p. contacter Dr. Hugh Geiger, Président du Comité des Prix d'Excellence, Geology and Geophysics Dept., University of Calgary, Calgary AB, T2N 1N4 (Email: geiger@ucalgary.ca, Fax: 403-284-0074). Les nominations doivent être supportées de trois lettres de recommandation de colléques. Les nominations doivent être soumises avant le 28 février, 2007. Des détails additionnels concernant le processus de nomination peuvent être obtenus en communiquant avec le Président du Comité des Prix d'Excellence de l'UGC.

***Past Winners***

2005 Shawn J. Marshall, J. Michael Waddington
2006 No winner

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## CGU Meritorious Service Award – Call for Nominations

The Executive of the CGU solicits nominations for the CGU Meritorious Service Award – 2007. The CGU Meritorious Service Award recognizes extraordinary and unselfish contributions to the operation and management of the Canadian Geophysical Union by a member of the CGU. All members of the CGU are eligible for this award, although the award is not normally given to someone who has received another major award (e.g. the J. Tuzo Wilson Medal). Nominations for the CGU Meritorious Service Award may be submitted by CGU members at any time. The award is made by the CGU Executive based on recommendations from the CGU Awards Committee, and is based on lifetime contributions to CGU activities.

If you would like to nominate a candidate, please contact Dr. Hugh Geiger, Chair of the CGU Awards Committee, Geology and Geophysics Dept., University of Calgary, Calgary AB, T2N 1N4 (Email: geiger@ucalgary.ca, Fax: 403-284-0074). The nomination should be supported by three letters of recommendation from colleagues. Nominations should be submitted by February 28, 2007. Additional details concerning the nomination process can be obtained from the Chair of the CGU Awards Committee.

L'exécutif de l'UGC vous invite à suggérer des candidats pour le Prix pour Service Méritoire de l'UGC – 2007. Le Prix pour Service Méritoire de l'UGC reconnait les contributions extraordinaires et désintéressées à l'opération et à l'administration de l'Union Géophysique Canadienne par un membre de l'UGC. Tous les membres de l'UGC sont éligibles pour ce prix, sauf que normalement, ce prix n'est pas donné à quelqu'un qui a recu un autre prix important tel que la Médaille Tuzo Wilson. Des nominations pour le Prix pour Service Méritoire de l'UGC peuvent être soumises en tout temps par les membres de l'UGC. Le Prix est accordé par l'Exécutif de l'UGC sur recommendations du Comité des Prix de l'UGC, pour l'ensemble des contributions d'un membre aux activités de l'UGC.

Si vous désirez suggérer un candidat pour cette médaille, s.v.p. contacter Dr. Hugh Geiger, Président du Comité des Prix d'Excellence, Geology and Geophysics Dept., University of Calgary, Calgary AB, T2N 1N4 (Email: geiger@ucalgary.ca, Fax: 403-284-0074). Les nominations doivent être supportées de trois lettres de recommandation de colléques. Les nominations doivent être soumises avant le 28 février, 2007. Des détails additionnels concernant le processus de nomination peuvent être obtenus en communiquant avec le Président du Comité des Prix d'Excellence de l'UGC.

***Past Winners***

2004 Ron Kurtz
2005 Ted Glenn
2006 J.A. Rod Blais

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## Expanded Abstracts of the CGU 2006 Best Student Papers – the D.M. Gray Award in Hydrology (C. Ellis), the Geodesy Award (M. Abd El-Gelil), and the Campbell Scientific Award (K.F. Ali) :

## Estimating Shortwave Irradiance through Forest Canopies on Complex Terrain

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**Abstract**
Methods for estimating below canopy shortwave irradiance in complex terrain are needed for energy balance snowmelt models and evaluations of the impact of forest cover change in mountains. This paper outlines a model to estimate sub-canopy shortwave irradiance over complex terrain through (i) geometric adjustment of shortwave irradiance at a level surface and (ii) the determination of forest transmissivity to shortwave irradiance. Geometric adjustment of shortwave irradiance was performed by approximating the amount received along the beam-path (*kb*) and from the rest of the sky hemisphere (*kd*) as determined by an atmospheric transmissivity index (*kt*). Adjustments of shortwave irradiance to a southeast-facing slope using the relation *kd*=1.08-1.09*kt* provided best estimates, having a RMSE within 8.3% of observed daily totals. Forest transmissivity of shortwave irradiance was calculated as the sum of the transmissivities of *kb* and *kd*. Transmissivity of *kb* was determined through calculating the respective fractions of surface area covered by non-transmitting trunks, partially-transmitting crowns and fully-transmitting gaps. By using (i) estimates of sub-canopy *kb* and (ii) observations of sub-canopy and above-canopy shortwave irradiance at a level forest, an approximation of forest transmissivity to *kd* is made. Compared to observations of sub-canopy shortwave irradiance, most reliable estimations are made for a southeast-facing forest and least reliable for a north-facing forest.

### Introduction
Runoff from mountain snowmelt is the main contributor to North American river flows. The combination of high relief and forest cover complicates the distribution of shortwave irradiance which represents the most important energy source driving sub-canopy melt (Link and Marks, 1999). Thus, prediction of mountain snowmelt requires accurate estimation of both above-canopy shortwave irradiance and its transmission through the forest layer. Despite methods to predict sub-canopy shortwave irradiance in level forests, many of these are not readily transferable to complex terrain due to the assumption that shortwave irradiance is transmitted through a continuous canopy layer. The objective of this paper is to outline and evaluate a method estimating sub-canopy shortwave irradiance which accounts for differences in both topography and forest cover density.

### Site description/instrumentation
The study was conducted within the Marmot Creek Research Basin (50°57`N, 115°09`W) located in the Rocky Mountains of southern Alberta. Shortwave irradiance was measured by Kipp and Zonen pyranometers located within level and southeast-facing clearings. Sub-canopy shortwave irradiance was measured by Kipp and Zonen pyranometers positioned beneath level, southeast-facing (125° aspect, 26° slope) and north-facing (351° aspect, 29° slope) forests.

**Estimation of above-canopy shortwave irradiance.** Distribution of shortwave irradiance ($K\downarrow$) from a level surface to a surface of given orientation requires information of the geometry of the incoming shortwave flux. $K\downarrow$ may be divided into the fraction received along the beam path (*kb*) and from the rest of the sky hemisphere (*kd*). Thus, $K\downarrow$ for a surface of orientation *S* is calculated by independent geometric corrections of *kb* and *kd* at level surface *L* via (after Tian, 2001)

$$K\downarrow_{(S)} = K\downarrow_{(L)}(kb)\left(\frac{S\wedge Z}{L\wedge Z}\right) + K\downarrow_{(L)}\,(kd)[(1+\cos\Delta)/2] \quad (1)$$

where $K\downarrow_{(S)}$ is the estimated shortwave irradiance at surface *S*, $K\downarrow_{(L)}$ is the shortwave irradiance at level *L*, and and $S\wedge Z$ and $L\wedge Z$ are the respective angles between the normals of surfaces *S* and *L* to the beam path. An assumption of [1] is the isotropic sky distribution of diffuse irradiance, which is reduced by an amount equal to the fraction of the sky hemisphere obstructed by topography.

Due to a lack of diffuse shortwave irradiance measurements, *kb* and *kd* may be approximated using an atmospheric transmissivity index (*kt*), determined by

$$kt = \frac{K\downarrow_{(L)}}{Kex_{(L)}} \qquad (2)$$

where $Kex_{(L)}$ is the observed and extra-terrestrial shortwave irradiance at level surface *L*. Commonly, *kd* is specified as a function of *kt* (*kd*=*f*(*kt*)) using direct measurements of beam and diffuse shortwave irradiance. However, the effectiveness of using of such empirical relations outside of the region where developed is uncertain (Jackovides et al., in press). Instead, a suitable *kt-kd* relation for the Canadian Rockies was resolved by comparing observations of $K\downarrow$ at a surface of 125° aspect, 26° slope to estimates via [1] using various *kd* values prescribed by the linear relation *kd*=*a*(*kt*)-*b*. Best comparison to observations for the period DOY 72-90 was provided using

$$kd = 1.08 - 1.09kt \qquad (3)$$

having a RMSE within 8.3% of daily totals of observed shortwave irradiance.

## Estimation of sub-canopy shortwave irradiance

Upon determining the fraction of above-canopy *kb* and *kd*, sub-canopy shortwave irradiance ($K_{sc}\downarrow$) is provided by calculating the respective direct and diffuse transmissivities through the forest layer. Transmissivity of *kb* (τ*kb*) is calculated by approximating the fraction of surface area occupied by non-transmitting trunks, partially-transmitting crowns, and fully transmitting gaps along the beam-path. Thus, τ*kb* for the time interval *t* to *t*` is expressed

$$\tau kb = \int_{t}^{t`} dkb\, dfG\, dt + dkb\, dfC\, d\tau_{(fC)}\, dt \qquad (4)$$

where *fG* is the gap fraction area, *fC* is the crown fraction area and $\tau_{(fC)}$ is the transmissivity of *fC* to *kb*. Fraction areas are determined in order of increasing transmissivity, with the area occupied by a formerly resolved fraction is unavailable to the next, such that

$$\begin{aligned} fC &= C(1 - fT) \\ fG &= G(1 - (fT + fC)) \end{aligned} \qquad (5)$$

where *fT* is the trunk fraction area, and *C* and *G* are the potential crown and gap fraction areas, respectively. To compute *fT*, the area of a single representative trunk ($\psi$) along the beam path at solar elevation angle $\theta$ is first determined by

$$\psi(\theta) = w\,\{h \cdot \cot[\theta + \Delta]\} \qquad (6)$$

where *w* and *h* are the respective representative trunk width and height as determined from field surveys, and Δ is the slope incline. From this, the fraction of surface area *A* shadowed by *n* representative trunks at solar elevation $\theta$ is approximated (after Federer, 1970)

$$fT(\theta) = 1 - \exp[-\left( \psi(\theta) / A(\theta) \right) \cdot n] \qquad (7)$$

By replacing *w* in [5] with the radius (*r*) of a single representative crown ($\xi$), the fractional area shadowed by *n* crowns at solar elevation $\theta$ is approximated as,

$$fC(\theta) = [1 - fT(\theta)] \cdot [1 - \exp(-\left( r\,\{h \cdot \cot[\theta + \Delta]\} / A(\theta) \right) \cdot n)] \qquad (8)$$

Transmissivity of beam irradiance through the crown fraction is calculated by the modified Beer's Law expression

$$\tau_{(fC)} = \exp[-u(\theta) l(\theta)] \qquad (9)$$

where *l* is the optical pathlength and the extinction coefficient, *u* is related to $\theta$ by (Pomeroy and Dion, 1996)

$$u(\theta) = [0.781\theta \cos(\theta) + 0.0591] \frac{LAI`}{H} \qquad (10)$$

in which *LAI*` is the effective leaf-area-index and *H* is the stand height. Pathlength, (*l*) through the crown fraction at $\theta$ is estimated by pathlength through a single representative crown ($\xi$) multiplied by the amount of crown overlap

$$l(\theta) = \frac{Volume\ of\ cone}{Area\ shadowed\ by\ cone(\theta)} \cdot \frac{n \cdot \xi(\theta)}{1 - \exp[-\left(\xi(\theta)/A(\theta)\right) \cdot n]} \quad (11)$$

Transmissivity of *kd* through the forest layer ($\tau kd$) is calculated from (i) the estimated beam irradiance transmitted to the sub-canopy ($beamK_{sc}\downarrow$) (ii) the estimated above-canopy diffuse irradiance ($K_D$) and (iii) observed total sub-canopy shortwave irradiance ($K_{sc}\downarrow$) at a level forest by

$$\tau kd = \frac{(total\ K_{sc}\downarrow - beamK_{sc}\downarrow)}{K_D(above-canopy)} \quad (12)$$

Overall, data requirements of the model include:

(i) incoming shortwave irradiance at an exposed, level surface

(ii) incoming shortwave irradiance below a level forest

and information describing

(iii) tree density per unit area of forest

(iv) trunk height, crown height, trunk width (dbh), crown base radius and

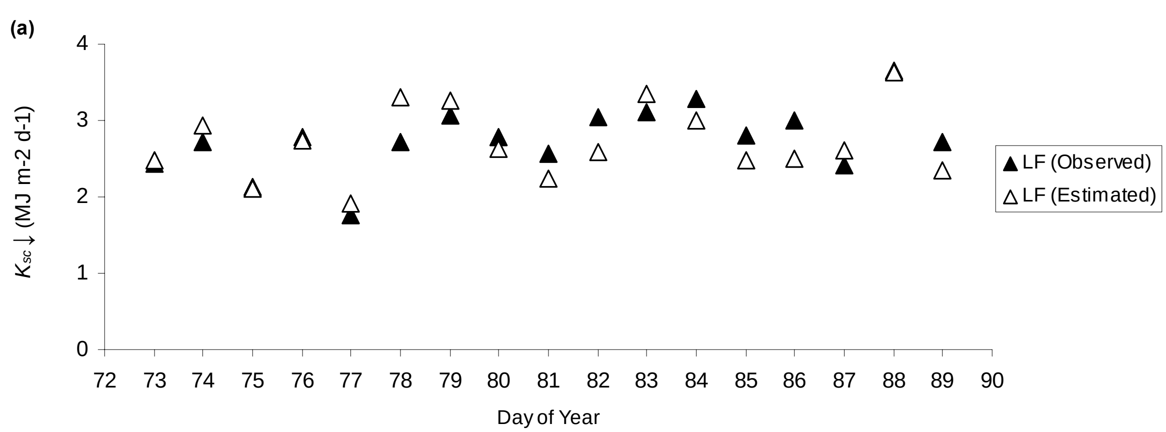
(v) leaf area index (or effective leaf area index)

(vi) topography (slope and aspect)

Statistical comparisons of estimated and observed $K_{sc}\downarrow$ for forests on surfaces of level, southeast-facing and north-facing aspects are provided in Table 2. Time series of daily total estimated and observed $K_{sc}\downarrow$ for each site are shown in Fig. 1.

Table 2. Measured parameters at level, south-facing and north-facing forest sites from field surveys and statistical comparisons of estimated to observed daily $K_{sc}\downarrow$ (RMSE is stated in terms of % observed daily total $K_{sc}\downarrow$).

| | Forest site parameters | | | | | Estimated vs. observed $K_{sc}\downarrow$ | |
|---|---|---|---|---|---|---|---|
| Site | Forest density (m2/tree) | Mean trunk height (m) | Mean crown height (m) | Mean crown Base radius (m) | Effective LAI (m2 m-2) | Standard error (MJ m-2 d-1) | RMSE (% daily observed) |
| Level forest | 2.23 | 11.2 | 3.3 | 1.6 | 1.40 | 0.28 | 10.5 |
| Southeast-facing forest | 3.60 | 11.0 | 3.5 | 1.3 | 1.32 | 0.30 | 7.6 |
| North-facing forest | 1.83 | 10.4 | 5.0 | 1.6 | 1.42 | 0.17 | 102.1 |



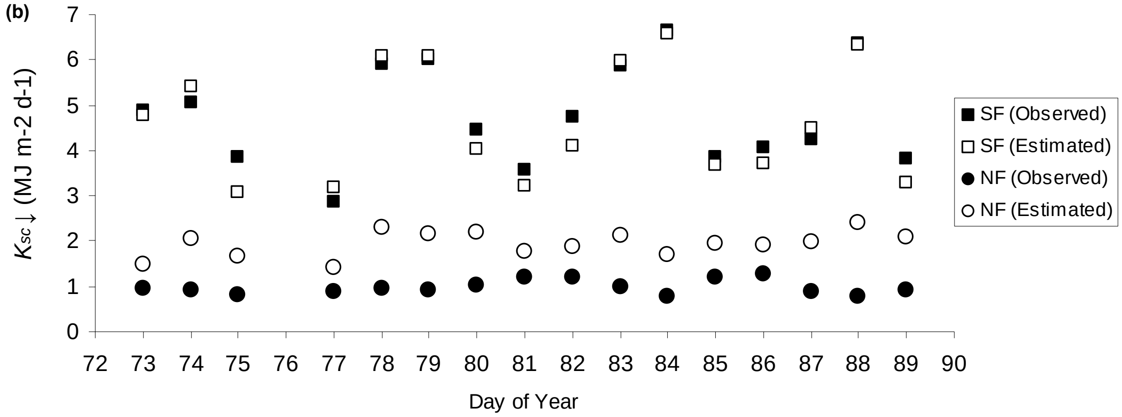



Figure 1. Time series of estimated and observed daily $K_{sc}\downarrow$ at (a) level forest (LF) and (b) southeast-facing (SF) and north-facing (NF) forest sites (days 76 omitted in due to snow on the pyranometer dome).

## Sensitivity Analysis

Figure 2 shows the sensitivity of model predictions of $K_{sc}\downarrow$ to (a) forest density ratio and (b) the fraction of beam irradiance-to-total shortwave irradiance (*kb*) at all forest sites. For the sensitivity trials, both (a) and (b) all forest parameters were set equal at all forest sites. Changes in forest density have the greatest effect on $K_{sc}\downarrow$ at the level forest and least effect at the north-facing forest. The fraction of above-canopy shortwave irradiance received as beam radiation has the least influence of $K_{sc}\downarrow$ at the north-facing forest and most for the southeast-facing forest.

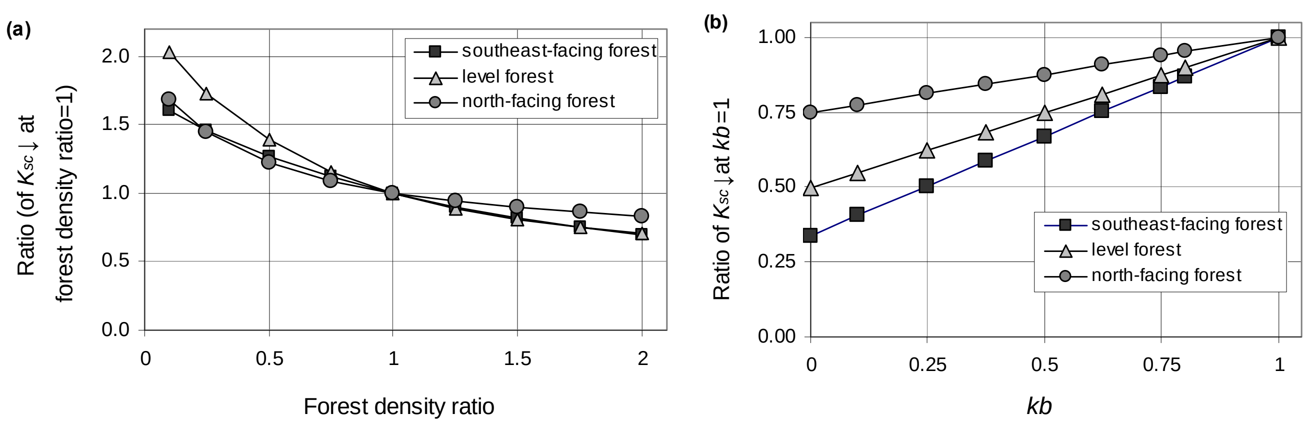



Figure 2 (a). Sensitivity of $K_{sc}\downarrow$ to change in forest density (forest stand ratio of 1=1tree/3.2 $m^{-2}$) and (b) sensitivity of $K_{sc}\downarrow$ to fraction of beam-to-total shortwave irradiance (*kb*).

## Discussion

Accurate estimation of sub-canopy shortwave irradiance is reliant upon both accurate determinations of above-canopy shortwave irradiance and its transmission through the forest layer. Topographic correction of shortwave irradiance may provide good prediction of above-canopy irradiance at a given slope and aspect, but information regarding the geometry of the incoming shortwave flux is required. Use of the relation *kd*=1.08-1.09*kt* provided best estimation of the respective beam and diffuse fractions of irradiance; however, this consistently overestimates beam irradiance compared to direct measurements. This inconsistency may be attributed to the improper assumption in [1] that diffuse irradiance is completely isotropic throughout the sky hemisphere (Kondratyev, 1969). Consequently, use of direct measurements of beam and diffuse irradiance in formulations similar to [1] may lead to increased estimation errors, especially on days of high shortwave irradiance.

Comparison of estimated to observed $K_{sc}\downarrow$ (Fig 1) show the model satisfactorily estimate irradiance at the southeast-facing forest, but not at the north-facing forest. This is a result of the inability of the model to properly distribute diffuse radiation, which contributes nearly all sub-canopy shortwave irradiance on north-facing forests. Errors resulting from poor estimation of diffuse radiation are likely produced from (i) improper assumption of isotropic distribution of diffuse radiation (ii) approximation of the transmissivity of diffuse irradiance through the southeast- and north-facing forests using estimated and observed irradiance data at the level forest. Hutchinson et al. (1980) observed most diffuse radiation incident to a deciduous forest canopy was received within 10 degrees of the shortwave disk during both clear and partly-cloudy skies. Accordingly, greater diffuse radiation would be expected beneath forests of more southern aspect due to both greater above-canopy diffuse radiation and increased transmissivity due to canopy gaps along the southern exposure of the forest. By contrast, north-facing forests would receive reduced sub-canopy diffuse irradiance as less is available to penetrate north-facing canopy gaps.

With further improvements in the distribution of diffuse irradiance; this new model has some potential to efficiently calculate satisfactory estimations of $K_{sc}\downarrow$ over complex terrain. The division of surfaces into trunk, crown and gap faction areas is advantageous as it accounts for transmission of beam irradiance through discontinuous forest canopies, but avoids the extremely complex calculations and vast parameter requirements of models such as GORT (Strahler et al., 1996). It is also of utility as the required forest parameters may be retrieved from forest inventories, satellite imagery or newly developing remote sensing technologies such as LIDAR.

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# Atmospheric Density Admittance Function for Gravity Reduction

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## 1. Introduction

Recent rapid improvements in technology has created extremely precise measuring systems that are affected by the smallest effects that were once much too small to be detected. The superconducting gravimeter is no exception; it is a sensitive device, which can detect minute changes in surface gravity at the nanogal level. Gravity variations are caused by many physical phenomena e.g. lunar and solar tides, Earth rotation, atmospheric and ocean loading, and others (e.g., Crossley and Xu, 1998; Goodkind, 1999; Hinderer and Crossley, 2000). It is, with no doubt, a challenge to identify and/or separate minute signal(s) of interest in a specific band of interest.

Atmospheric mass change is one of the most significant environmental phenomena that affects Earth surface gravity. There are two approaches that are usually followed to model the atmospheric pressure effect on gravity signals: physical and empirical. The latter is also called "*the admittance function*" or "*the transfer function*" method and represents the response of gravity to atmospheric pressure variation. In this paper we take a new approach that allows us to model the response of gravity to air density variations rather than to the air pressure as it has traditionally been done. The atmospheric correction to gravity is achieved by using air density time series that are synthetically produced from temperature, pressure and humidity time series recorded simultaneously with gravity at Canada's fundamental gravity station, in Cantley PQ.

A constant admittance is not adequate to describe the air pressure or density effect, which is admittedly frequency dependent. This frequency-dependent admittance that was first introduced by Warburton and Goodkind, (1977) and later by Crossley et al., (1995), Neumeyer, (1995) and others, shows that it increases smoothly and monotonically from 0.2 μgal/mbar at low frequencies (<0.3 cpd) to about 0.35 μgal/mbar at high frequencies (>1 cpd). However, Sun et al., (2002) found that the admittance is 0.378 μgal/mbar at low frequencies and decreases to 0.147 μgal/mbar at high frequencies.

In this paper, we adopt an alternative approach for the determination of the admittance that is based on the least-squares (LS) product spectrum of the air density and gravity time series. The air density is synthetically produced from pressure, temperature and humidity records using the equation of state of the atmosphere. The air density admittance is then estimated from common spectral peaks identified in the gravity and air density series, using the product spectrum and rigorous statistical analysis tools. The common spectral peaks in both gravity and air density series are suppressed to estimate their amplitudes and phases and subsequently the yearly admittance amplitude and phase in the band 700h to 2h. Finally, the weighted LS regression is used to estimate the admittance as a function of frequency.

## 2. Atmospheric Density

The atmospheric density can be calculated using the equation of state of the atmosphere, which after some lengthy derivation gives the total air density as a function air pressure *P*, temperature *T:*

$$\rho = \frac{P}{R_d T_v}, \qquad T_v = \left( \frac{1 + \frac{r}{\varepsilon}}{1 + r} \right) T, \tag{1}$$

where $R_d$ is the specific gas constant for dry air, $T_v$ is the virtual temperature, $r$ is the mixing ratio and $\varepsilon$ is the ratio between specific dry and wet gas constants ($\varepsilon$ = 0.6221).

## 3. Methodology

We use the Least Squares Spectral Analysis (LSSA) to estimate the spectra of the gravity and air density series and subsequently produce their product LS spectrum. More details on the LSSA and related statistical properties can be found in Vanicek (1969; 1971) and Pagiatakis, (1999).

The LSSA spectrum is described by the percentage variance $s(\omega_i)$ of the spectral content of a time series $f(t)$ with variance-covariance $C_f$ at a specific frequency $\omega_i$:

$$s(\omega_i) = \frac{f^T C_f^{-1} \hat{p}(\omega_i)}{f^T C_f^{-1} f}, \tag{2}$$

where $\hat{p}(\omega_i)$ is the projection of $f(t)$ on a manifold characterized by a specific base functions (trigonometric function). It has been shown (Pagiatakis, 1999) that the probability density function (*pdf*) of the LS spectrum is the *beta* distribution, which can be used to define the *pdf* of the product of two LS spectra using standard statistical approaches (e.g. Hogg and Craig, 1995). After lengthy derivations, the *pdf* of the product LS spectrum *z* for two random variables $x_1$ and $x_2$ is:

$$f(z) = \int_z^0 \beta_1 \beta_2 e^z \left(1 - e^{z - x_2}\right)^{\beta_1 - 1} \left(1 - e^{x_2}\right)^{\beta_2 - 1} dx_2, \tag{3}$$

where $\beta_i = 0.5(m_i - u_i - 2)$, $m_i$ is the length of time series and $u_i$ is the number of unknown parameters estimated by the LS procedures. The above *pdf* that underlines the product LS spectrum can be used to identify statistically significant common peaks in both gravity and air density series via their product spectrum.

The statistically significant common peaks (periods) in the product spectrum are suppressed separately in the gravity and air density series to estimate their amplitude and phase:

$$g_i = a_{iG}(\cos(\omega_i t) - \varphi_{iG}), \tag{4}$$

$$\rho_i = a_{i\rho}(\cos(\omega_i t) - \varphi_{i\rho}), \tag{5}$$

where $a_{iG}$, $a_{i\rho}$ are the amplitudes of gravity and air density constituents, respectively and $\varphi_{iG}$, $\varphi_{i\rho}$ are their phases. The magnitude and phase of the air density admittance is then estimated from:

$$\alpha(\omega_i) = \frac{a_{iG}}{a_{i\rho}}, \tag{6}$$

$$\Delta\varphi_i = \varphi_{iG} - \varphi_{i\rho} \tag{7}$$

## 4. Data processing and Analysis

Three year long time series of gravity, air pressure, temperature and humidity starting 1st January 2000 are used to estimate the air density admittance. First, the solid Earth tide effect is removed from the 1s gravity records using GWAVE (Merriam, 1992). The ocean loading effect is also removed by least-squares fitting of eight most significant periods; this is done simultaneously with the estimation of the gravity spectrum using the LSSA software. The 1s gravity residual series is then filtered using a Parzen weighting scheme that produces unequally spaced series along with their standard deviation at a sampling interval ranging from 2 to 5 minutes. The air density and its associated standard deviation are predicted every 30 minutes using Eq. (1).

The product LS spectrum of gravity and air density is then calculated from the two individual LS spectra respectively to show common peaks. Subsequently, the product spectrum and its statistical properties are used to estimate the Earth gravity response to air density. Yearly data are processed to estimate the spectrum in the band 700h to 2h (0.0014cph to 0.5cph). The statistically significant common peaks (95 percent confidence level) in the product spectrum are identified using the *pdf* given by Eq. (3). The periods of these peaks are then suppressed in each of the gravity and air pressure series provided that they are also statistically significant (at 95 percent) in these series. The suppression of the significant periods gives an estimate of their amplitudes and phases. The magnitude of the air density admittance along with its standard deviation is estimated for the period of three years (Fig. 1). The weighted LS regression is used to define the best fit to three years admittances (μgal/$g^{-1}m^3$):

$$\alpha(f) = 0.13261 - 0.08965 e^{\left(-\frac{1}{240 f}\right)} \quad (8)$$

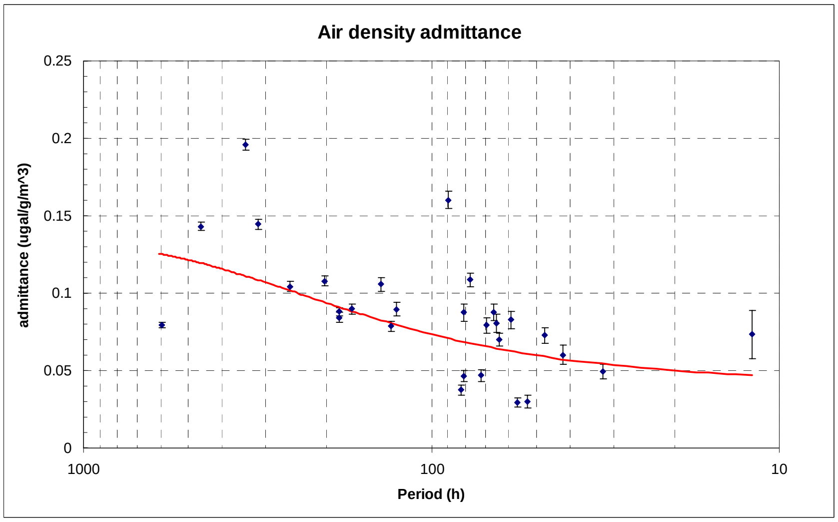


Fig. 1 Air density admittance as a function of period (h)

## 5. Discussion and conclusion

The new air density admittance is frequency dependent. It is relatively constant in the high frequency band; it increases exponentially starting from 24h. The combination of the three physical environmental effects namely, pressure, temperature, and humidity through the equation of state of the atmosphere (physical law) is expected to improve the signal-to-noise ratio in the gravity spectrum, more than the pressure admittance alone. Research is continuing to determine the seasonal variations of the air density admittance.

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# Factors Controlling Sediment Yield in a Major South Asian Drainage Basin: The Upper Indus River, Northern Pakistan

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## Overview

Studies of the factors controlling sediment yield in large drainage basins show that variables reflecting runoff magnitude and basin relief characteristics are most strongly associated with sediment yields (Summerfield and Hulton, 1994; Ludwig and Probst, 1998; Hovius, 1998). The recent growth in the availability of global environmental datasets containing topographical, geomorpological, hydroclimatic and biological characteristics provides an opportunity to examine systematically the relationships between sediment yields and controlling catchment variables using modern GIS techniques. The main objective of this study is to examine the major controlling factors of sediment yield in the upper Indus basin using high resolution, spatially distributed data extracted from various global datasets utilizing modern Hydro Data Model techniques (ESRI, 2006), and to develop regression models for estimating sediment yield in the upper Indus basins. This study is also an effort to contribute to the Predictions in Ungauged Basins (PUB) initiative (IAHS, 2003) which includes: i) prediction of the fluxes of water associated constituents from ungauged basins by developing new modelling approaches; ii) an understanding of different climatic and landscape controls on hydrologic processes occurring at different scales; and iii) a demonstration of the value of data for hydrologic predictions and alternative data sources.

## Study area

The Indus River is one of the largest rivers in southern Asia, and extends across portions of Pakistan, India, China and Afghanistan. The upper Indus River basin upstream of Tarbela Dam is 1125 km long, with a drainage area of 181,500 km$^2$. The Indus River rises in the Tibetan Plateau at elevations above 5500 m. Much of its flow originates in the mountains of the Karakoram and Himalayas, and it transports large volumes of sediment, the majority of it in suspension.

## Data and methods

Long-term continuous discharge and occasional suspended sediment concentration data are available for 17 active and discontinued gauging stations in the upper Indus River basin and their drainage areas range from 598 to 166,154 km$^2$. In addition to 7 runoff and sediment variables, a total of 21 characteristics were derived from spatially distributed topographic, climatic, anthropogenic and land cover datasets available in public domain. For deriving the topographic variables, a window covering the upper Indus River basin was extracted from 30-second resolution USGS GTOPO30 DEM. Point coverage of the stream gauging stations was generated from their latitude and longitude. Using the extracted DEM window and the gauging stations coverage, sub-basin segmentation and parameterization were carried out with Arc Hydro Tools (ESRI, 2006). A total of 14 variables, including sub-basin area, channel length, mean elevation, basin relief, relief ratio and mean surface slope were derived for each of the 17 sub-basins. The climate data were derived from two sources: i) Legates and Willmott (1992) 30-minute resolution dataset; and ii) 1-km$^2$ WORLCLIM database (Hijmans *et al*., 2005). The extracted variables included mean annual precipitation, mean annual temperature, maximum monthly precipitation, precipitation peakedness, and temperature range. The percent snow/ice cover was extracted from 1-km resolution USGS global land cover characteristics database.

## Results

To reduce the scatter between specific sediment yield and controlling variables, the basin was subdivided into the following four subgroups based on the subdivision made by Ali and de Boer (2006) for delineating the spatial patterns of sediment yield in terms of climatic and hydrological regimes of the basin: i) the whole basin; ii) the main Indus River; iii) the upper glacierized sub-basins; and iv) the lower monsoon sub-basins. Multiple regression models were developed for estimating specific sediment yield in each of the subgroups. A manual procedure was used for selecting the independent variables so that the variables: i) showed a significant correlation with specific sediment yield; ii) they were independent of each other; and iii) had physical relevance to the particular sub-group. The models along with their assessment and validation parameters are shown in Table 1. A multiple regression model, including the specific runoff and percent snow/ice cover, explains 47.6% of the variance for the whole basin. The basin sub-grouping shows a remarkable impact on regression models with $R^2_{adg}$ values rising to 95.9, 94.1 and 69.5% for the main Indus River, glacierized sub-basins and monsoon sub-basins, respectively. The specific runoff and percent snow/ice cover explain a 94.1% variance for the upper glacierized sub-basins as compared to 47.6% for the whole basin. The model for the main Indus River is different, with basin relief and population density as the main controlling variables in addition to specific runoff. These three parameters explain 95.9% of the variance. The lower monsoon region shows somewhat different behaviour, and 69.5% of the variance is explained by discharge peakedness and mean annual precipitation. The validity of the regression models was determined by applying a paired *t*-test and by calculating the model efficiency (*ME*) after Nash and Sutcliffe (1970). The model efficiency (*ME*) can range from -∞ to 1 and represents the proportion of the initial variance accounted for by the model. The closer the value of ME approaches 1, the more efficient the model is. It is notable that all of the models pass the paired *t*-test with calculated *t* value considerably smaller than critical value, $t_{cr}$ (Table 1). Moreover, *ME* values approaching to 1 and the nearness of $R^2$ and $R^2_{adj}$ values indicate that the models are robust and predict well the specific sediment yield in different regions of the upper Indus basin.

Table 1. Regression models predicting suspended sediment yield in the upper Indus River basin

| Regression Models | $R^2$ | $R^2_{adj}$ | $t$ | $t_{cr}$ | $ME$ |
|---|---|---|---|---|---|
| The whole basin<br>$SY_{sp} = 244 + 0.742\ RO + 39.6\ LC_s$ | 54.2% | 47.6% | 0.01 | 2.12 | 0.542 |
| The Main Indus River<br>$SY_{sp} = -\ 1987 + 0.259\ RO + 260\ R_r + 59.8\ PD$ | 97.9% | 95.9% | 0.10 | 2.45 | 0.980 |
| Upper glacierized sub-basins<br>$SY_{sp} = -\ 98 - 0.104\ RO + 72.5\ LC_s$ | 95.2% | 94.1% | 0.00 | 2.20 | 0.951 |
| Lower monsoon sub-basins<br>$SY_{sp} = -\ 5614 + 66124\ Q_{pk} + 3.91\ P$ | 89.9% | 69.5% | 0.07 | 2.78 | 0.889 |

*$SY_{sp}$ = specific sediment yield (t $km^{-2}$ $yr^{-1}$); RO = specific runoff (mm $yr^{-1}$); $LC_s$ = percent snow/ice cover (%); $R_r$ = relief ratio; PD = population density (humans $km^{-2}$); $Q_{pk}$ = discharge peakedness; P = mean annual precipitation (mm $yr^{-1}$)*

## Conclusions

The specific runoff and percent snow/ice cover emerge as major controls on sediment yield in the upper Indus River basin at regional scale. These parameters are also strongly correlated to relief, slope and precipitation parameters. This shows that drainage basin scale variation of sediment yield in the Indus River basin depends on the combined effects of precipitation, runoff, relief and percent snow/ice cover for sediment production and transport processes. None of the other variables seem to be a major control on sediment yield on regional scale in the upper Indus River basin. In other regional scale studies, Lu and Higgit (1999) found specific runoff and mean elevation to be significantly correlated with sediment yield in the upper Yangtze River basin, whereas, Restrepo *et al.* (2006) found that specific runoff and maximum annual water discharge explained most of the variance in observed sediment yields for the

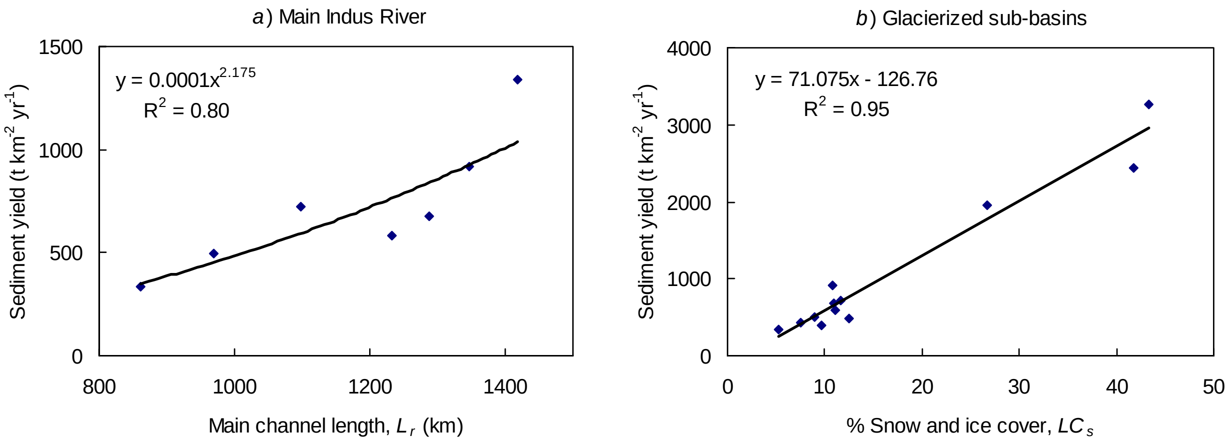


Fig. 1. Relationships between sediment yield and selected sub-basin variables

Magdalena River basin in Columbia. The subdivision of the basin into smaller subgroups results in a better understanding of the dynamics of sediment yield in the basin. A strong correlation between sediment yield and channel length (Fig. 1a) suggests a considerable impact of bank and bed erosion for the main Indus River. Percent snow/ice cover appear to be the major control in the upper glacierized sub-basins (Fig. 1b). For the lower monsoon part, the mean annual rainfall and peak discharges seem to be dominant stimulants in eroding the material and transporting it. The emergent parameters for the respective subgroups show a strong physical relevance to the respective sub-basin characteristics. The basin grouping also proves to be useful in constructing spatially distributed multiple regression models that present valuable tools for predicting specific sediment yield in the upper Indus basin by using six variables that include specific runoff, percent snow/ice cover, relief ratio, population density, discharge peakedness and mean annual precipitation. The variables used are capable of explaining the majority of variance in the comparatively 'natural' upper glacierized tributaries, but are less adequate in the lower, monsoon-affected region because of data scarcity. Further improvements in the resolution and accessibility of other environmental datasets in terms of soil properties and geology may allow a more detailed analysis and an improved understanding of sediment dynamics at drainage basin scale. As the sparse gauging network in this large basin is rapidly decreasing in density, the upper Indus also represents a good case study for investigating the sediment dynamics of a large mountainous data-sparse river basin as a contribution to the Prediction in Ungauged Basins (PUB) program (Sivapalan, 2003).

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**CMOS-CGU-AMS 2007 / SCMO-UGC-AMS 2007**

**Air, océan, terre et glace sur le Roc**
**28 mai au 1er juin, 2007**

## Appel de communications

**Congrès SCMO-UGC-AMS 2007**
**St-Jean, Terre-Neuve, Canada**
**28 mai au 1er juin, 2007**

Le congrès 2007 de la Société canadienne de météorologie et d'océanographie (SCMO), de l'Union géophysique canadienne (UCG) et de l'American Meteorological Society (AMS) (comités de météorologie et d'océanographie polaire, de la variabilité du climat et des interactions air-mer), en partenariat avec le Eastern Snow Conference (ESC), sera tenu au St. John's Convention Centre et à l'hôtel Delta de Terre-Neuve, du 28 mai au 1er juin, 2007.

Le thème du congrès, "Air, océan, terre et glace sur le Roc", ainsi que les objectifs de l'Année polaire internationale, reflètent l'objectif du congrès qui est d'explorer, d'échanger et d'intégrer les intérêts scientifiques de la SCMO, de l'UGC, de l'AMS et du ESC. Pour plus d'information sur les sessions spéciales et générales qui sont planifiées visitez le site du congrès à http://www.cmos2007.ca.

La date limite pour soumettre un résumé est le 15 février, 2007. Les résumés doivent être soumis électroniquement en anglais ou en français sur le site du congrès au http://www.cmos2007.ca. Les résumés doivent contenir moins de 300 mots et ne pas contenir de graphiques.

Pour plus d'information sur les sessions scientifiques, contactez les co-présidents du comité du programme scientifique : Guoqi Han (SCMO) à HanG@dfo-mpo.gc.ca, Rod Blais (UGC) à blais@ucalgary.ca, ou Taneil Uttal (AMS) à Taneil.Uttal@noaa.gov. Pour d'autres informations générales à propos du congrès visitez http://www.cmos2007.ca ou contactez le président du comité des arrangements locaux Fraser Davidson au DavidsonF@dfo-mpo.gc.ca.

CMOS SCMO

**CMOS-CGU-AMS 2007 / SCMO-UGC-AMS 2007**

**Air, Ocean, Earth and Ice on the Rock**
**May 28-June 1, 2007**

## Call for Papers

**CMOS-CGU-AMS Congress 2007**
**St. John's, Newfoundland, Canada**
**May 28 – June 1, 2007**

The Canadian Meteorological and Oceanographic Society (CMOS), the Canadian Geophysical Union (CGU), the American Meteorological Society (AMS) (Polar Meteorology and Oceanography, Climate Variability and Air-Sea Interactions Committees) Congress 2007 together with the Eastern Snow Conference (ESC) will be held at the St. John's Convention Centre and Delta Hotel in Newfoundland Canada from May 28 to June 1, 2007.

The Congress theme, "Air, Ocean, Earth and Ice on the Rock", along with the key objectives of the International Polar Year, reflects the Congress' objective to explore, link, bridge and integrate the scientific interests of the CMOS, CGU, AMS and ESC. For information on planned special and general science sessions, please visit the Congress web site at http://www.cmos2007.ca.

The deadline for submission of abstracts is February 15, 2007. Abstracts should be submitted electronically in English or French on the Congress web site at http://www.cmos2007.ca. Abstracts should be no more than 300 words, with no figures.

For enquires on scientific sessions, please contact the co-chairs of the Scientific Program Committee: Guoqi Han (CMOS) at HanG@dfo-mpo.gc.ca, Rod Blais (CGU) at blais@ucalgary.ca, or Taneil Uttal (AMS) at Taneil.Uttal@noaa.gov. For other information on the Congress, visit http://www.cmos2007.ca or contact Local Arrangement Committee chair Fraser Davidson at DavidsonF@dfo-mpo.gc.ca.

## The University of Western Ontario

## Department of Earth Sciences

## Assistant Professor in GEOPHYSICS

**The Department of Earth Sciences is pleased to announce a search for an Assistant Professor in Geophysics. The starting date for the appointment will be July 1, 2007 or thereafter.**

The Department of Earth Sciences (http://www.uwo.ca/earth) at The University of Western Ontario is seeking a new junior faculty member to join its geophysics group. Building upon existing and developing areas of strength in mineral physics and seismology, this appointment is a direct outgrowth of the recently established NSERC and Benfield/ICLR Industrial Research Chair (IRC) in Earthquake Hazard Assessment. The successful candidate will normally be appointed at the rank of Assistant Professor (probationary tenure-track), and is expected to teach at both the undergraduate and graduate levels. The successful candidate will also be expected to establish and maintain a vigorous, independently funded research program.

Funded by both NSERC and an insurance industry partnership, the primary aim of the IRC program is to improve quantitative earthquake hazard studies and their scientific, engineering, and economic implications, through innovative research into earthquake forecasting, hazard analysis, and the user-scientist communication interface. A synopsis of the IRC goals is available at www.uwo.ca/earth. We are seeking applicants who will complement this program, ideally with expertise in one or more areas such as: the physics of earthquakes; fracture mechanics; and modeling of earthquake dynamics. Researchers with expertise in other fields will also be considered. A rationale must be provided that clearly links the applicant's expertise to the IRC program.

The closing date for applications is **January 15, 2007**. A detailed curriculum vitae, a research plan, and the names of three referees should be sent to:


Dr. H. Wayne Nesbitt
Chair, Department of Earth Sciences
The University of Western Ontario
London, Ontario CANADA N6A 5B7


*This position is subject to budgetary approval. Applicants should have fluent written and oral communication skills in English. All qualified candidates are encouraged to apply; however, Canadians and permanent residents will be given priority. The University of Western Ontario is committed to employment equity and welcomes applications from all qualified women and men, including visible minorities, aboriginal people and persons with disabilities.*

## Post-Doctoral Fellow in Alpine Hydrology, University of Calgary

The University of Calgary is seeking a postdoctoral research fellow in hydrological research of alpine environments. The role of groundwater in alpine streams and lakes in the Canadian Rockies has previously been neglected, but recent field studies suggest that groundwater contribution may be very important (Hood et al., 2006. *Geophys. Res. Lett.*, 33, doi:10.1029/2006GL026611). The fellow will conduct field-based research at the Lake O'Hara research basin in Yoho National Park to determine the hydrological functions of groundwater in the alpine environment and their responses to climatic fluctuations. The ideal candidate for this position will have a strong background in physical hydrology. Research experiences in glaciology, hydrogeophysics, biogeochemical cycles, and aquatic ecology will be considered an asset. The position is for up to three years and will start as a suitable person is found. To apply for the position, please send a current CV, statement of research interest, and name and contact information of three references to Dr. Masaki Hayashi (e-mail: hayashi@ucalgary.ca) at the Department of Geology and Geophysics (http://www.geo.ucalgary.ca/hydro/).

## OFFICERS OF THE CGU EXECUTIVE COMMITTEE



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***Editor's Note*: ELEMENTS, the newsletter for the Canadian Geophysical Union, is published and distributed to all CGU members twice each year; one Summer issue and one Winter issue. We welcome submissions from members regarding meeting announcements or summaries, awards, division news, etc. Advertisements for employment opportunities in geophysics will be included for a nominal charge (contact the Editor). Notices of post-doctoral fellowship positions available will be included free of charge.**

**General submissions should be sent to the Editor:**
**Prof. E.S. Krebes, Geology and Geophysics Dept., University of Calgary, Calgary, Alberta, Canada, T2N 1N4. Telephone: (403) 220-5028; Fax: (403) 284-0074; Email: krebes@ucalgary.ca.**

**Hydrology-specific submissions should be sent to:**
**Dr. Garry Thorne, Email: thorneg@aecl.ca.**

**Geodesy-specific submissions should be sent to:**
**Prof. Marcelo Santos, Email: msantos@unb.ca**

**Electronic submission is encouraged.**